B. Mangan Smith: My name is Betty Mangan Smith from Vista Santa Rosa. I've lived here 26 years. My well, like Gayle's, is disappearing and I can't yell and scream and give the speech I was going to because you nice people are here and the people I need to yell at aren't. However, I am going to bring up his name. Tom Levy, how can you say a few years ago (this is to Gayle's quote) that our grandchildren and their lawyers will be fighting for water in the courts. This was published in the Desert Sun. And now you say we have plenty of water for development. I think he talks out of both sides of his mouth. **20** **20-1**

Right now we talk about all this lovely water we're going to get off the Colorado River. Well, Lake Powell, that tremendous big body of water north of the Colorado River is down 60 feet and as of the last week in July, the water in that magnificent basin dropped 1 foot total throughout that entire basin in 1 week. That's the water that we're relying on. That says to me CAUTION. **20-2**

Now, NASA in January predicted decades of draught. I know, now we are talking of El Niño, but which of you present can tell the future? I can't. I don't know that your people can.

Developers are using right now our good drinking water to keep the dust down up in Whitewater. At the last air quality meeting, we had one of your board members state, "We do not have enough water for what you people are asking." And that was the use of water to keep the dust down in the desert for the developers. Guess what? It's being done anyway. Twenty-four hours a day, water trucks are on the roll up in the Whitewater area. What good does it do? The water evaporates all too quickly. It's good drinking water by the way. The hot air evaporates it and, I don't know, I just get the whole feeling that the greed of the politicians and developers, and I hope not to say the water company but maybe, are going to ruin this valley and let the small people already here take their lumps. Sorry farmers, you can no longer farm one of the most fertile valleys in the world. You know the little conch shell that makes the minerals that go into the vegetables? They're covered out there. The Nile river is the first. We're the second according to Robert Lloyd who built the water system which is considered in agricultural areas around the world as the Sphinx. Foreign dignitaries from agriculture come over every year to look at that and they are awed by the system that was done by Allen Trover's father, Robert Lloyd. **20-3**

One of the other things besides the farmers is, "Sorry citizens of the Coachella Valley. Oops, we ran out of water. You'll all have to move. Sorry we let so much water run down the gutter and streets and poured so much into the desert sands. As for your people who came here for your health. That's too bad too." We once had a healing desert. But no more. It's hard to breathe the air. I think all of you notice that. Today is probably one of the clearest days we've had in I don't know how long.

When are you people going to start using your heads? I have a question. I came in a little late. I know you have been trying to put water back into our aquifer down here, but have to date put any water back into the aquifer? Any of you, I don't care. How much? **20-4**

Mr. Robbins: Almost 2,000,000 acre-feet.

Ms. Mangan Smith: And has the aquifer risen?

Answer: Yes.

Ms. Mangan Smith: And is this water cleaned in any way or is it just brought in from the Colorado River and dumped into our wonder, pristine source of water?

Answer: Just dumped.

Ms. Mangan Smith: Just dumped. Yep, that would figure. Okay. All I ask the small people of the valley to do is get out there and write your letters, pay attention to what these people are doing because it's your future. **20-5**

20. Response to: Betty Mangan Smith Vista Santa Rosa, CA

20-1 While there is water in the basin sufficient to provide addition development for at least 35 years, the groundwater level is falling and pumping from greater depth will be increasingly expensive. In addition, as discussed in the Draft PEIR, there are other overdraft impacts projected, including water quality and land subsidence. A goal of the Water Management Plan is to slow and eventually stop this decline in groundwater levels, restoring the sustainability of the long-term water supply.

20-2 The proposed sources of water for the Water Management Plan are discussed in the Draft PEIR Sections 2 and 3. Lakes Powell and Mead were designed to store water in times of high runoff for use in dry periods like the current conditions. The drop in water levels is typical of what is expected during dry conditions. These reservoirs are expected to refill during normal years. The large storage volume of the Coachella Valley groundwater basin provides a similar buffer between wet and dry years. The District has developed the Water Management Plan to address the uncertainties associated with future droughts.

20-3 The District does not have control over land use planning decisions, but works with the Coachella Valley cities and the County of Riverside to encourage water conservation and the use of xeriscape. CVWD has been implementing conservation measures for many years and will continue to do so. CVWD is currently working with the Coachella Valley cities to reduce water use by golf courses and landscaping. One measure being pursued is revision of the cities' existing landscaping ordinances. Currently, these ordinances specify newly installed and rehabilitated landscaping have a maximum applied water allowance of 0.8 times the reference evapotranspiration (ET_o). CVWD proposes to reduce the water allowance to 0.6 times ET_o. This will reduce landscape water use by 25 percent. CVWD will consider inclusion of incentives for retrofitting existing golf courses to be more water efficient. The District appreciates EPA providing the attached information "Environmental Principles for Golf Courses in the U.S." and will consider these conservation measures in the preparation of future water conservation plans.

20-4 The Whitewater Spreading Facility in the Upper Valley has recharged almost1,800,000 acre-ft into the Coachella Valley aquifers since 1973. The Dike 4 pilot recharge project has been recharging on a test basis for several years in the Lower Valley.

20-5 The Colorado River water that enters the Coachella Valley and is recharged is not treated before recharge. No pre-recharge treatment is required because, as the water travels through several hundred feet of soil before reaching the water table, suspended material in the water is removed. The aquifer soils function an enormous filtration system.

Gail Cady: Good afternoon. My name is Gail Cady. I live in the community of Vista Santa Rosa. I was having some fun on the computer today and I came across some article, I will just read part of it. It is entitled, *Putting Dreams into Actions*. It is regarding the natural resources of water. It says: Of all natural resources, water is the most essential, but globally, 2 billion people live in areas with chronic water shortage and the United States is not exempt from these problems. The mighty Colorado River is so drained by irrigation and cities that its channels run dry part of the year. The Ogallala aquifer that waters one-fifth of all United States irrigated land is overdrawn by 12 billion cubic meters per year—a problem that has already caused more than 2 million acres of farmland to be taken out of irrigation. In California central valley which grows half the nation's fruit and vegetables, groundwater withdraw exceeds recharge by 1 billion cubic meters per year. **21**

The reason that I brought this information is because it truly did catch my attention. The main concern that I have about recharging the aquifer in the lower eastern Coachella Valley, which is the area that I live, is that the water that we are going to be recharging it with has to come from some place. If we are using the All American Canal and the Colorado River water and we are entitled to so many acre-feet per year, that's all well and good, but the way things are going with the drought in the western continental United States, my major concern is, is that water actually going to be available? I know there are no guarantees in life, but it is a major concern that I have. **21-1**

Secondly, I have a question for the water district and I do not know who to address this to. Does the water district have monitors on any wells that are over 6-inch in diameter for a recharge cost? In other words, the golf courses for instance. Frequently I see Rainbird-type sprinklers watering the golf courses mid day. Logically, my thought pattern is--well, it is pretty hot, it is 2:00 in the afternoon, the water is like 20 - 25 feet in the air. It is probably evaporating as much in the air as it is putting on the ground, the ground is already hot, so how much is going to evaporate before it actually gets to the bottom where the grass roots are? So again I am asking, how is it that we are monitoring the amount of water that the golf courses are using in comparison to say, the agricultural industry of our community? **21-2**

Yesterday evening I attended the public hearing that the water district had at the Palm Desert City council chambers and a question came up with regards to the equestrian contribution to our community. Also, there is a question with regards to any other communities that might be perhaps entertaining an equestrian-type facility and/or a comingling of various other entities in the community for instance, CVAG, Parks and Recreation, the cities, etc., regarding completing and implementing a trail system throughout the Coachella Valley. This is a little off the subject but I just want everyone to know that I am going to be giving these to the water district board to copy for review. This is an economic impact projection for the Indio Desert Circuit. For those of you that do not know, this is a horse show that is put on in Indio every year. I think it runs about 10 weeks. It has Olympic-level jumping competition. People come from all over the world for this particular event. In this particular stack of paper is simply the Desert Horse Show. This does not include any of the polo activities or any of the other horse events. Additionally, I have from the American Horse Council in Washington, D.C., horse industry statistics for the year 2002. And last but not least, I have the goals and policies of the Thousand Oaks General Plan which collectively that community has manage to have a connective trail system. 21-3

21. Response to: Gayle Cady Vista Santa Rosa, CA

21-1 There are currently about 28 million acre-ft of groundwater stored in the Coachella Valley. This large storage volume acts as an effective buffer for period droughts such as that currently being experienced. This year is one of the lowest runoff years on record and yet the USBR is able to meet all demands for Colorado River water. This is possible because of the large reservoirs on the Colorado River like Lake Mead and Lake Powell. See Response 20-2.

21-2 CVWD currently requires meters on all Upper Valley golf course and other larger wells in the Upper Valley. These meter readings are used to determine replenishment assessments that are levied on all pumpers larger than 25 acre-ft/yr. In the future, CVWD plans to implement a replenishment assessment on all Lower Valley pumpers larger than 25 acre-ft/yr. At that time, CVWD will commence monitoring pumping of these wells. Irrigation of golf courses during the daytime is not a preferable activity, due to the increased evaporation. However, during extremely hot weather, the courses may need to apply water during the day to prevent burning of the grass.

21-3 The equestrian trail system would add a recreational resource to the Coachella Valley, but has no impact on the proposed Water Management Plan.

Lee Anderson: My name is Lee Anderson. I live at 59-777 Calhoun Street in the Thermal area. I don't really have much to add or I am not here to either support or refuse this plan. Just that I remember back, my father used to be on the water board here, he told me years ago when we got the canal water, he reminded me that this is only supplemental water—the canal water that we were getting. At that time they figured there would be enough water from the natural flows that we were getting to irrigate somewhere between 25,000 and 40,000 acres and that the canal water that we would get in to supplement that would be enough for about a little over 3 acre-feet per acre with the agricultural water that we had. I remember before we got the canal water how in our particular area we had to—our water table was dropping about 10 feet a year and we had to lower the bowls on our pump twice before we got the canal water. And then as you all remember we used a lot of canal water and then we had so much water that we had to drain the water—we had to tile the line to take off the surface water. My concern is right now, all of the pumps in our area are—the water table is lowering in our area. It seems to me that there is a lot of "ifs" in this program and we are talking 2035. I am just wondering, can I still pump water, will I still have water availability for my area until 2035? I am concerned about that. As you well recognize at the time we received the canal water, there was not a lot of the recreation area. There has been so much area that has taken so much of that water right now—that is my concern. 22

22-1

22 Response to: Lee Anderson
59-777 Calhoun Street
Thermal, CA

22-1 The District shares your concern for the long-term availability of water. The Coachella Valley Water Management Plan was prepared to address these long-term concerns. The District believes that implementation of the Plan will ensure your ability, along with the entire Valley's ability, to have adequate supplies of groundwater available in 2035 and beyond.

The projections presented in the Draft PEIR indicate that groundwater levels in the Thermal area would decrease by about 30 ft by the year 2015 and about 90 ft by the year 2035 compared to 1999 levels if the Proposed Project is not implemented (see Figures 6-23 and 6-24 of the Draft PEIR). The Proposed Project is expected to increase groundwater levels by about 20 ft in 2015 and by about 50 ft in 2035 compared to current conditions (see Figures 6-25 and 6-26 of the Draft PEIR). Consequently, the District believes that there will more than adequate water availability for your area until 2035 if the Proposed Project is implemented.

Master Response on Perchlorate

INTRODUCTION

The Draft Program Environmental Impact Report (PEIR) has identified the potential for increased perchlorate concentrations in groundwater wells as a potentially significant impact of the Proposed Project. Mitigation has been proposed to reduce this impact to less than significant by providing treatment for any drinking water supplies that exceed public health standards based on monitoring the quality of groundwater produced from drinking water wells located near the proposed groundwater recharge areas. Proposed mitigation includes working with the well owners to bring their drinking water supply into compliance by either providing domestic water service from the CVWD or DWA domestic water systems or by providing appropriate well-head treatment, if monitoring shows that the groundwater pumped from these wells exceeds any health-based drinking water standard due to recharge activities.

Perchlorate (ClO_4^-) is a contaminant from the solid salts of ammonium, potassium or sodium perchlorate. Ammonium perchlorate has been used as an oxygen-adding component in solid fuel propellant for rockets, missiles and fireworks. Perchlorate compounds are also used in air bag inflators, nuclear reactors, electronic tubes, lubricating oils, electronic plating, aluminum refining, leather tanning and finishing, rubber and fabric manufacture and in the production of paints, enamels and dyes. Perchlorate is highly mobile in water and can persist under typical groundwater and surface water conditions for decades. Perchlorate is known to interfere with the uptake of iodine by the thyroid gland. Because iodine is an essential component of thyroid hormones, perchlorate disrupts the function of the thyroid gland. Perchlorate is among the unregulated chemicals requiring monitoring (Title 22, California Code of Regulations §64450). It is "unregulated" because it has no drinking water standard or maximum contaminant level (MCL).

PERCHLORATE STANDARDS

Several commenters stated that Colorado River water contains "dangerous" levels of perchlorate and that any perchlorate in the recharge water was unacceptable. These conclusions are a function of the criteria used to determine the significance of the perchlorate concentrations in Colorado River water. Therefore some explanation of the development of perchlorate regulations is needed.

There are some misconceptions regarding the current health standards for perchlorate. First, there is no adopted enforceable standard for perchlorate in drinking water. The US Environmental Protection Agency's (EPA) National Center for Environmental Assessment (NCEA) issued a *draft* toxicity assessment for perchlorate that included a *draft* reference dose (RfD) of 0.00003 milligrams per kilogram per day (mg/kg/day). The RfD is defined as an estimate, with uncertainty spanning perhaps an order of magnitude (ten-fold), of a daily exposure to the human population (including sensitive subgroups such as pregnant women, children and people with compromised thyroid conditions) that is likely to be without appreciable risk of adverse effects over a lifetime. EPA used a lowest observed adverse effects level (LOAEL) of 0.01 mg/kg/day as determined from animal studies. This LOAEL was divided by a composite uncertainty factor of 300 that accounts for 1) human sensitivity, 2) the duration of health studies and 3) database quality to compute the draft RfD of 0.00003 mg/kg/day.

The EPA assessment provided a hypothetical conversion of the draft RfD to a drinking water equivalent level (DWEL), assuming factors of 70 kilograms (kg) for body weight and 2 liters (L) of water consumption per day. The converted draft estimate would be 1 microgram per liter (μg/L) or 1 part per billion (ppb), assuming drinking water is the sole source of perchlorate. If EPA were to make a determination to regulate perchlorate, the RfD along with other considerations would factor into the final value. At this point in time, the EPA has not determined whether to regulate perchlorate in drinking water. If the EPA decides to regulate perchlorate, the RfD along with other health effects information, economic considerations, and technical feasibility would be used to establish a federal MCL. However, any federal standard would be established after California promulgates its own MCL. The Safe Drinking Water Act requires that any California drinking water standard must be at least as stringent as the federal MCL.

On its website, EPA states: "*As with any EPA draft assessment document containing a quantitative risk value, that risk value is also draft and should not at that stage be construed to represent EPA policy. Thus, the draft RfD for perchlorate is still undergoing science review and deliberations both by the external scientific community and within the Agency.* " (emphasis added). The draft RfD is not an adopted standard. Instead, it serves as a starting point for establishing a drinking water standard. The RfD is currently undergoing scientific peer review; a report by its peer review committee was released in June 2002. EPA is currently reviewing the peer review report and public comments. EPA expects to release a revised draft; however, no date has been given for its release. Given the on-going review, it is premature to ascribe a maximum perchlorate concentration based on the current draft risk assessment.

Similarly, the State of California Office of Environmental Health Hazard Assessment (OEHHA) issued a *draft* public health goal (PHG) for perchlorate of 6 μg/L. This PHG was based on results of human studies that established a "no observed adverse effects level" of 0.01 mg/kg/day and an uncertainty factor of 30. The PHG is calculated using a 65 kg body weight, 2 L/day water consumption and 60 percent of daily perchlorate exposure from drinking water. A public workshop on the PHG was held on April 29 and a revised draft should be available by late summer 2002. OEHHA expects to finalize the PHG by the end of 2002.

The California Department of Health Services (DHS) established a health-based action level for perchlorate of 18 μg/L in 1997. The California Health & Safety Code §116455 requires a drinking water system to notify the governing body of the local agency in which users of the drinking water reside (*i.e.*, city council and/or county board of supervisors) when a contaminant in excess of an action level or a MCL is discovered in drinking water well, or when the well is closed due to the contaminant's presence. DHS recommends that the drinking water system take the source out of service if a contaminant is present at more than 10 times the action level. In the case of perchlorate, this would currently be a concentration of 40 μg/L.

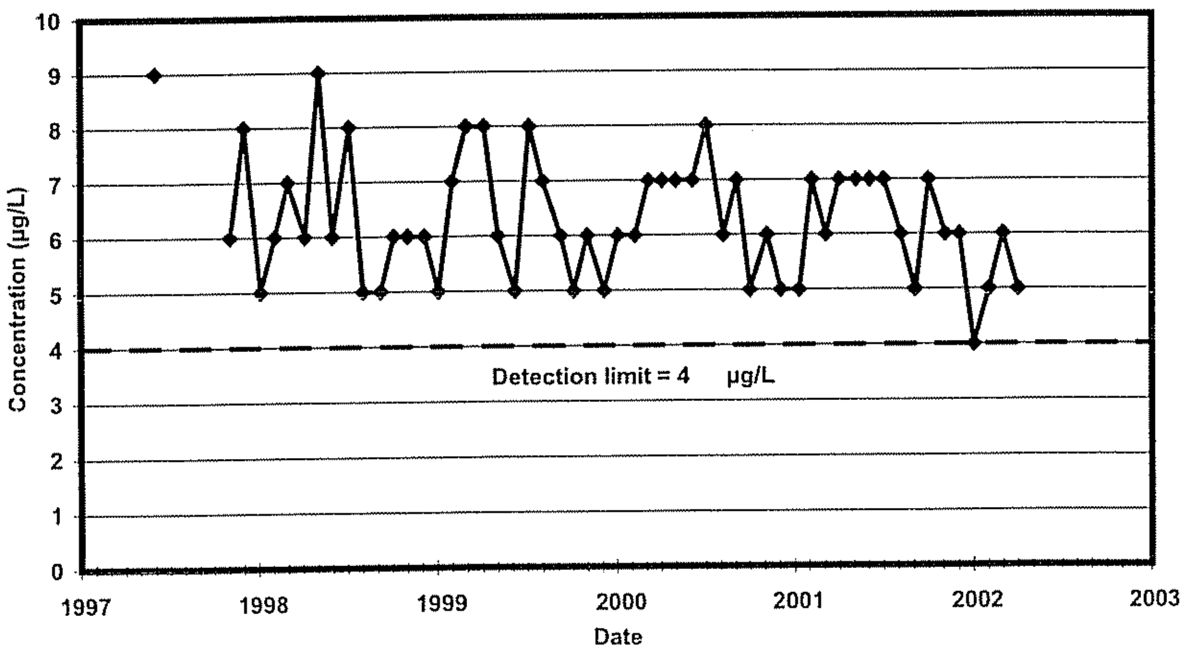
In January 2002, the EPA NCEA released a draft revised risk assessment for perchlorate which concluded that the health risks associated with perchlorate are greater than previously determined. As a result of the release of the draft NCEA health risk assessment, DHS lowered its action level for perchlorate from 18 µg/L to 4 µg/L, which is the detection limit (January 2002). Senate Bill 1822 (Sher), which calls for OEHHA to establish a PHG by January 1, 2003 and for DHS to adopt a primary drinking water standard by January 1, 2004 signed by the Governor on September 8, 2002..

In summary, it is premature to adopt a drinking water standard for perchlorate concentrations without considering the scientific evidence. Consequently, the current action level of 4 µg/L is used as a threshold for significance recognizing that the ultimate MCL could be higher than the action level.

SOURCE AND DISPOSITION OF PERCHLORATE

Perchlorate was initially detected by Metropolitan at a level of 9 µg/L at Lake Havasu (see **Figure 5-8** of the Draft PEIR and repeated below). Recent measurements at Lake Havasu have been in the range of 4 to 6 µg/L. In 2001 and 2002, IID detected perchlorate in the All-American Canal system ranging from 4.2 to 5.3 µg/L.

Figure 1
Perchlorate Concentrations in Colorado River Aqueduct Water



The source of perchlorate in Colorado River water has been determined to be the Kerr-McGee Chemical Company and the former PEPCON perchlorate manufacturing facilities in Henderson, Nevada. Perchlorate waste from decades of poor disposal practices has permeated into the groundwater under the manufacturing site which flows into Las Vegas Wash and then into Lake

Mead. Kerr-McGee, working with the Nevada Division of Environmental Protection (NDEP), constructed a slurry wall to slow the migration of the perchlorate plume to Las Vegas Wash, began extracting perchlorate-contaminated groundwater, and has operated an interim 450 gpm groundwater treatment system since 1999. Kerr-McGee began operation of a larger (825 gpm) treatment facility in late March 2002 (S. Crowley, Kerr-McGee, pers. comm. 2002) which is expected to significantly reduce the perchlorate entering Lake Mead (Metropolitan, 2002b).

The Southern Nevada Water Authority (SNWA) monitors the quality of water in Las Vegas Wash and reports that the concentration of perchlorate has fallen by approximately 40 to 50 percent in less than two years (K. Vickman, SNWA, pers. comm., 2002). Similarly, Metropolitan has observed similar reductions since 1997. The future perchlorate concentration in Colorado River water that reaches the All-American and Coachella Canals is difficult to predict because of diluting river flows and Lake Mead levels whose variability depends on meteorological factors and river operations. Metropolitan is working with a consultant to develop a perchlorate washout model. This model is expected to show the future expected perchlorate levels at their Lake Havasu diversion. The USBR and the SNWA are potential partners in this effort (Metropolitan, 2002b). Nevertheless, perchlorate concentrations are anticipated to decrease further over time.

PERCHLORATE TREATMENT

Several commenters suggested that perchlorate mitigation should include pre-recharge treatment and requested cost comparisons for pre-recharge and post-extraction treatment. The available treatment methods and the cost of treatment prior to recharge are discussed below.

Perchlorate Treatment Alternatives

In addition to site remediation, perchlorate can be separated from drinking water using a variety of technologies.

Treatment options for perchlorate removal from drinking water include physicochemical processes such as granular activated carbon (GAC) adsorption, ion exchange, and membrane separation, and biological processes such as anaerobic treatment. Because perchlorate is highly oxidized and does not absorb radiation in the ultraviolet light spectrum, neither oxidation technologies (e.g., ozone or UV/hydrogen peroxide) nor ultraviolet irradiation (e.g., low pressure, medium pressure, or pulsed UV) reduce perchlorate.

Removal by GAC is difficult and expensive because of the high solubility of perchlorate. The efficiency of ion exchange is reduced because ions such as nitrate and sulfate interfere with perchlorate adsorption. Also, regeneration of the ion exchange resin creates a salt brine that can cause disposal problems because of high perchlorate concentrations. Note that ion exchange is viable as a site remediation strategy when extremely high levels of perchlorate occur, e.g., in contaminated groundwater (100,000 – 300,000 µg/L). It is less effective when concentrations are less than 100 µg/L. Recent pilot tests of ion exchange treatment for perchlorate removal indicate that trace amounts of N-nitrosodimethylamine (NDMA), a known animal carcinogen, are released into the product water from the ion exchange resins.

Reverse osmosis and nanofiltration membranes are effective removal technologies but merely transfer the perchlorate to the waste brine. Biological treatment has been shown to be effective with highly contaminated wastewater and groundwater. It is not clear whether bioreactors would produce potable drinking water from sources with the low levels of perchlorate, such as found in drinking water supplies. DHS, however, recently issued conditional approval for the use of a biological process using a fluidized bed of granular activated carbon for perchlorate removal from water that is a potential source of drinking water supply. Biological treatment requires the addition of a carbon source such as ethanol and nutrients to the water for microbial growth. At this time, there are too little operational data available to show that large-scale use of biological treatment for low levels of perchlorate is feasible.

Implementation of any of these technologies could take up to five years. Remediation at the source is a more effective method for reducing perchlorate levels within a comparable timeframe.

Perchlorate Treatment Costs

Given the shortcomings of the other processes, ion exchange has been applied in a number of locations to remove perchlorate. Options for ion exchange treatment include pre-treatment before recharge and post-treatment of the extracted groundwater.

Ion exchange treatment prior to recharge in the Coachella Valley would require three facilities having the following capacities:

Table 1
Perchlorate Treatment Facilities Design Capacities

Facility	Design Capacity[1]	Average Annual Flow
Whitewater Spreading Facility	250 mgd	140,000 acre-ft/yr[2]
Dike 4 Spreading Facility	72 mgd	40,000 acre-ft/yr
Martinez Canyon Spreading Facility	72 mgd	40,000 acre-ft/yr

1 Design capacity is based on recharging the average annual flow within a six month off-peak demand period.
2 Note that the average recharge at Whitewater would be 140,000 acre-ft/yr through 2007, decreasing to 103,000 acre-ft/yr by 2013.

The capital cost for ion exchange treatment facilities would be $260 million at the Whitewater facility and $74 million each for the Dike 4 and Martinez facilities, exclusive of brine disposal costs. The total capital cost for treatment would be $408 million. This high capital cost is dictated by the capacity of the treatment facilities, which are sized to recharge the desired amount of water within the six month off-peak period (October through March). Delivery of water for recharge during the peak demand months (April through September) is unlikely due to the need to serve direct users of Coachella Canal water and Metropolitan's need to meet demands in its service area with Colorado River water.

Table 2
Pre-Recharge Perchlorate Treatment Costs

	Whitewater Spreading Grounds	Dike 4	Martinez	Total
Capital Cost				
Ion Exchange	$180,000,000	$51,430,000	$51,430,000	$282,860,000
Contingency	$45,000,000	$12,860,000	$12,860,000	$70,720,000
Construction Cost	$225,000,000	$64,290,000	$64,290,000	$353,580,000
Engg & Admin	$33,750,000	$9,650,000	$9,650,000	$53,050,000
Land	$140,000	$40,000	$40,000	$220,000
Capital Cost	**$258,890,000**	**$73,980,000**	**$73,980,000**	**$406,850,000**
Operating Cost				
Amortized Capital	$20,260,000	$5,790,000	$5,790,000	$31,840,000
Fixed O&M	$5,180,000	$1,480,000	$1,480,000	$8,140,000
Salt	$6,710,000	$1,920,000	$1,920,000	$10,550,000
Total	**$32,150,000**	**$9,190,000**	**$9,190,000**	**$50,530,000**
Annual Flow (acre-ft/yr)	**140,000**	**40,000**	**40,000**	**220,000**
Unit Cost ($/acre-ft)	**$230**	**$230**	**$230**	**$230**

The total annual cost for all three facilities would be $50.5 million per year. Of this amount, about $40.8 million would be borne by CVWD and $9.7 million by DWA. This expenditure would increase CVWD's annual domestic water operating costs by 110 percent compared to current annual expenditures. This would require domestic water rates to more than double compared to current rates.

As noted previously, these costs do not include brine disposal. Approximately 100 tons of salt per year would be required for regeneration. The brine would contain large amounts of perchlorate as well as nitrate and sulfate. It is expected there would be significant environmental issues associated with brine disposal including land use, biological and cultural resources, and water quality.

Reverse osmosis treatment would remove salt (TDS) including perchlorate from the water. The cost for reverse osmosis treatment for the above recharge water flows to a TDS of 300 mg/L would be approximately $244 to $330/acre-ft as presented in the Appendix I of the Draft PEIR. These costs are from 5 percent to over 40 percent higher than that for ion exchange.

Facilities for post-recharge treatment of extracted water could have smaller capacities, since only drinking water supply would require treatment if their perchlorate concentrations exceeded the future perchlorate MCL. Water pumped for golf course irrigation or other non-potable uses would not receive treatment because perchlorate is not an issue for these uses. There are approximately 45 domestic water supply wells in the Upper Valley that could potentially be affected by water recharged at the Whitewater Spreading Facility based on data presented in the draft PEIR. These wells have an average capacity of about 2500 gpm (3.6 mgd, 162 mgd total). In addition, it is assumed that there are about 20 domestic wells in the Lower Valley that could be affected by recharge at the Dike 4 and Martinez Canyon sites with average capacities of about 500 gpm (0.7 mgd each, 14 mgd total). It is unlikely that all of these wells would experience elevated perchlorate concentrations due to dilution with native groundwater. Therefore, this estimate is extremely conservative.

If treatment were provided for all of these potentially affected wells, the total capital cost would be about $200 million and the total annual cost would be about $23 million, exclusive of brine disposal as shown in Table 3. Allocating the cost of treatment between DWA and CVWD based on their relative share of groundwater production results in about $6.3 million in additional cost for DWA and $16.4 million for CVWD. For CVWD, this cost represents a 50 percent increase in the current cost of domestic water.

Table 3
Groundwater Perchlorate Treatment Costs

	Whitewater Spreading Grounds	Dike 4	Martinez	Total
Capital Cost				
Ion Exchange	$116,640,000	$7,780,000	$2,600,000	$127,020,000
Contingency	$29,160,000	$1,950,000	$650,000	$31,760,000
Construction Cost	$145,800,000	$9,730,000	$3,250,000	$158,780,000
Engg & Admin	$21,870,000	$1,460,000	$490,000	$23,820,000
Land	$100,000	$20,000	$20,000	$140,000
Capital Cost	**$167,770,000**	**$11,210,000**	**$3,760,000**	**$182,740,000**
Operating Cost				
Amortized Capital	$13,130,000	$880,000	$300,000	$14,310,000
Fixed O&M	$3,360,000	$230,000	$80,000	$3,670,000
Salt	$4,350,000	$290,000	$100,000	$4,740,000
Total	**$20,840,000**	**$1,400,000**	**$480,000**	**$22,720,000**
Annual Flow (acre-ft/yr)	**90,720**	**6,048**	**2,016**	**98,784**
Unit Cost ($/acre-ft)	**$230**	**$231**	**$238**	**$230**

CONCLUSION

Given the uncertainty associated with the future drinking water standard for perchlorate, the current low concentrations in Colorado River water, the on-going clean-up activities in Las Vegas Wash, the expected reduction in future perchlorate concentrations, the high cost of treatment and uncertainties associated with brine disposal, CVWD believes treatment for perchlorate prior to recharge is not economically feasible and may not be necessary due to the on-going source control efforts at Las Vegas Wash. The cost of pre-treatment would more than double the cost of domestic water. Wellhead treatment could increase domestic water costs for CVWD by about 50 percent.

Appendix D

Coachella Valley Groundwater Model (Revised)

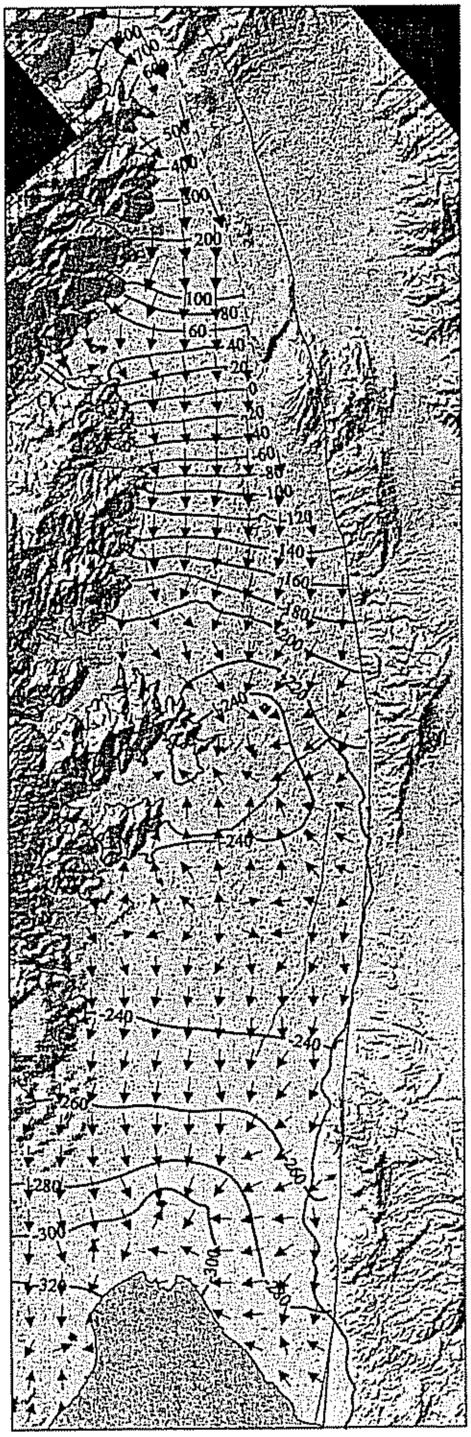
Appendix D of the Draft PEIR is hereby revised to include the two reports that follow:

Coachella Valley Groundwater Model, Peer Review Report, 1998.

Groundwater Flow Model of Coachella Valley, California: An Overview" prepared by Graham E. Fogg, Gerald T. O'Neill, Eric M. LaBolle and David J. Ringel,

Groundwater Flow Model of Coachella Valley, California: An Overview

Graham E. Fogg, Gerald T. O'Neill, Eric M. LaBolle, David J. Ringel



Prepared for
Coachella Valley Water District

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By Graham E. Fogg, Gerald T. O'Neill, Eric M. LaBolle, *and* David J. Ringel

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Prepared for
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1 EXECUTIVE SUMMARY

A three-dimensional, numerical groundwater flow model of the Coachella Valley, California was developed for Coachella Valley Water District (CVWD) to provide a scientific basis for managing groundwater in Coachella Valley into the next century. The purpose of the model is to test the effects of various management plan alternatives involving artificial recharge and reductions in pumpage on sustainability of groundwater levels, potential saline water intrusion from the Salton Sea, and potential land subsidence.

The model built upon previous modeling investigations by the United States Geological Survey (USGS) in the upper Coachella Valley. Tyley (1974), Swain (1978), and Reichard and Meadows (1992) all constructed two-dimensional groundwater flow models of the upper valley, each model representing an improvement over the previous. Tyley's model was an electric analog and the later efforts were based on the finite element method. Thus, the current three-dimensional model of the entire Coachella Valley is a logical extension of the previous models. The multiple layers of the present model are also necessary for representing multiple aquifer zones in the lower valley.

A historical period of 61 years, from 1936 through 1996, was used to calibrate the model. Comprehensive information on groundwater pumpage, natural recharge, and drain flows were compiled for this period. Data on groundwater parameters from well tests and records were interpreted together with regional geologic information to define the physical system within which the groundwater flows. Results are generally excellent, with groundwater levels computed by the model throughout the basin closely tracking the measured historical trends and elevations. Additionally, the model closely simulated historic trends and flows in measured agricultural drain discharges.

An independent committee consisting of three internationally recognized experts in the development and application of groundwater models conducted a peer review of the model. The committee concluded that the model is valid and could be used to evaluate the groundwater impacts of the management alternatives under consideration (Larson et. al, 1998).

2 INTRODUCTION

The Coachella Valley is a northwest-southeast trending valley over 50 miles in length (from the San Gorgonio Pass to the Salton Sea) and includes approximately 440 square miles. Coachella Valley lies in central Riverside County in the hot, arid Colorado Desert of California (Fig. 1). Precipitous and rugged mountains bound Coachella Valley, except to the southeast, where the valley drains into the Salton Sea. Elevations in the watershed range from over 10,000 ft above sea level in the San Bernardino and San Jacinto Mountains to lower than 200 ft below sea level at the Salton Sea. The valley floor ranges in elevation from over 1,200 ft above sea level in the San Gorgonio Pass to approximately 228 ft below sea level at the Salton Sea.

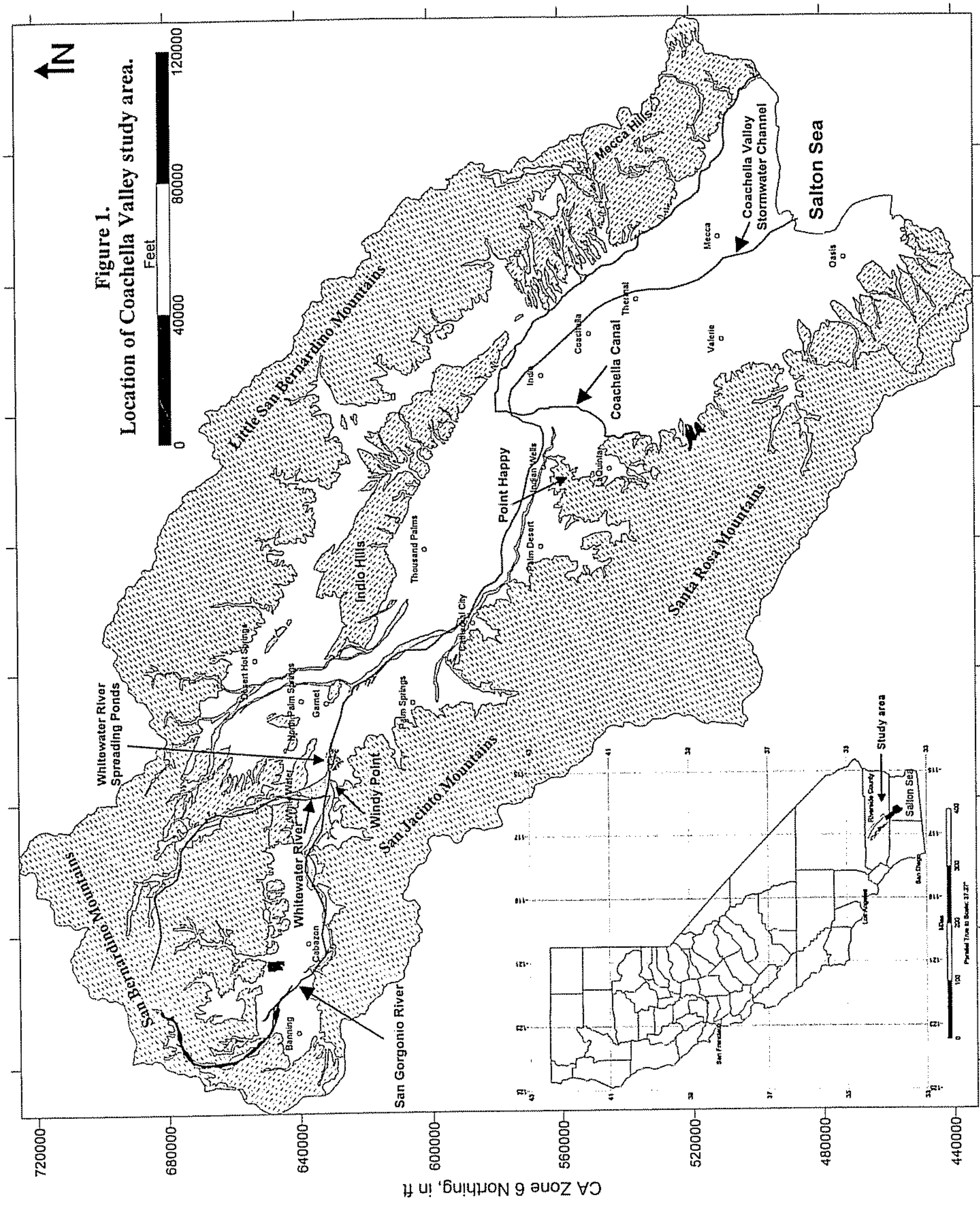


Figure 1.
Location of Coachella Valley study area.
Feet
0
40000
80000
120000
N
San Bernardino Mountains
Little San Bernardino Mountains
Mecca Hills
Indio Hills
San Jacinto Mountains
Santa Rosa Mountains
Whitewater River Spreading Ponds
Whitewater River
Windy Point
San Gorgonio River
Point Happy
Coachella Canal
Coachella Valley Stormwater Channel
Salton Sea
Banning
Cabazon
Desert Hot Springs
North Palm Springs
Garnet
Palm Springs
Cathedral City
Thousand Palms
Palm Desert
Indian Wells
La Quinta
Indio
Coachella
Thermal
Valerie
Mecca
Oasis
Study area
Riverside County
San Francisco
Los Angeles
San Diego
CA Zone 6 Easting, in ft
CA Zone 6 Northing, in ft
1800000
1840000
1880000
1920000
1960000
2000000
2040000
2080000
720000
680000
640000
600000
560000
520000
480000
440000

The valley is divided into an upper valley and lower valley near Point Happy (Fig. 1). The upper valley primarily consists of desert resort communities, while the lower valley has a predominantly, year-round, agricultural economy. These economies are dependent on water from surface water and groundwater sources. Resort communities in the upper valley rely on groundwater, which is supported by artificial recharge. Agricultural development in the lower valley uses groundwater as well as Coachella Canal water imported from the Colorado River. Surface water for artificial recharge and from the Coachella Canal was introduced to the valley after many years of groundwater pumping resulted in widespread declines in water levels throughout the basin. Still, demand on groundwater has increased over time, and has placed considerable stress on the aquifer system. These stresses have resulted in valley-wide overdraft and reversed hydraulic gradients in the lower basin. Additionally, potential land subsidence is a concern.

2.1 Previous Investigations

Previous hydrologic studies conducted in Coachella Valley include those of Mendenhall (1909), Kocher and Harper (1927), Pillsbury (1941), Huberty et al. (1948), and substantial work by California Department of Water Resources (1964; 1979). Detailed descriptions of the geology and hydrology of the Coachella Valley groundwater basin are provided in California Department of Water Resources (DWR, 1964) report *Coachella Valley Investigation*. USGS studies in the upper Coachella Valley, including the development of groundwater flow and transport models, include those of Tyley (1974), Swain (1978) and Reichard and Meadows (1992). These studies were motivated chiefly by the need to better understand and forecast effects of artificial recharge at the Whitewater River spreading ponds (Fig. 1), including water quality impacts of the recharge. However, no previous hydrologic modeling analysis had included the lower Coachella Valley, and very few estimates of pumpage or recharge from irrigated agriculture had been made. Consequently, the current study was designed to develop a model that included both the upper and lower Coachella Valley and estimates of historical agricultural groundwater pumpage in the lower valley for use in calibration.

2.2 Purpose and Scope

The purpose of the study was to (1) develop a comprehensive understanding of the groundwater hydrology of Coachella Valley, and (2) develop a three-dimensional groundwater flow model of the entire valley to provide a means of analyzing quantitatively the groundwater inflows and outflows in a management context.

The study consisted of extensive reexamination of the available groundwater data, developing improved estimates of pumpage and recharge, and construction of a three-dimensional groundwater flow model of most of the valley. The purpose of the model is to evaluate present and future management options in Coachella Valley. The model is designed to simulate groundwater flow throughout the basin, while addressing the limitations of previous models. The three-dimensionality of the model allows for good representation of the complex aquifer system in the lower valley. Furthermore, improved estimates of pumpage and recharge, representation of the massive drainage network underlying the agricultural lands, as well as interaction between the groundwater system and the Salton Sea are significant improvements relative to previous investigations.

2.3 *Well Numbering System*

The well numbering system used in this report is based on the rectangular system for subdivision of public land. Wells are numbered according to their location; for example 04S05E15J01S indicates the township (T. 4 S.), range (R. 5 E.), section (15), 40-acre subdivision of the section (J), and a serial number for wells in each 40-acre subdivision (1). The model area lies south and east of the San Bernardino base line and meridian. Figure 2 shows an overlay of the rectangular system on a digital base map of the Coachella Valley area.

2.4 *Hydrogeologic Setting*

Coachella Valley is located in the northwestern corner of the Colorado Desert physiographic province. It is bounded by the Peninsular (San Jacinto and Santa Rosa Mountains) and Transverse (San Bernardino and Little San Bernardino Mountains) Ranges. Much of the valley floor lies at low elevation; from Indio south to the Salton Sea, valley floor elevations are generally below mean sea level. The dominant feature of the Colorado Desert is the Salton Trough, a large structural depression that extends from San Gorgonio Pass south to the Gulf of Mexico (Norris and Webb, 1976). The Salton Basin refers to the region of the trough that drains directly into Salton Sea. The lower portion of the trough is occupied by the Colorado River delta and is entirely in Mexico. The San Andreas fault zone extends along the northeastern side of the basin. Thick Cenozoic sedimentary materials of primarily continental (nonmarine) origin underlie the Salton Basin and contain the major aquifer systems.

Climate in the valley consists of hot, arid summers; however, summer convection storms from the Gulf of California contribute as much as 40 percent of the annual rainfall on the valley floor. Warm dry winters prevail in the valley. Average annual rainfall on the valley floor is less than 5 inches, and does not contribute significantly to the usable water supply. Average annual precipitation on the San Bernardino and San Jacinto Mountains ranges from 30 to 40 inches, and natural recharge to the groundwater basin occurs from infiltration of mountain runoff. The Whitewater River and its tributaries, and the Coachella Valley Stormwater Channel (CVSC), drain the watershed (Fig. 1).

2.4.1 Geology

The geology of the Coachella Valley area has been studied in detail and documented in previous reports, including DWR (1964) and others (see Tyley, 1974); therefore, this section contains information pertinent only to understanding the groundwater flow system.

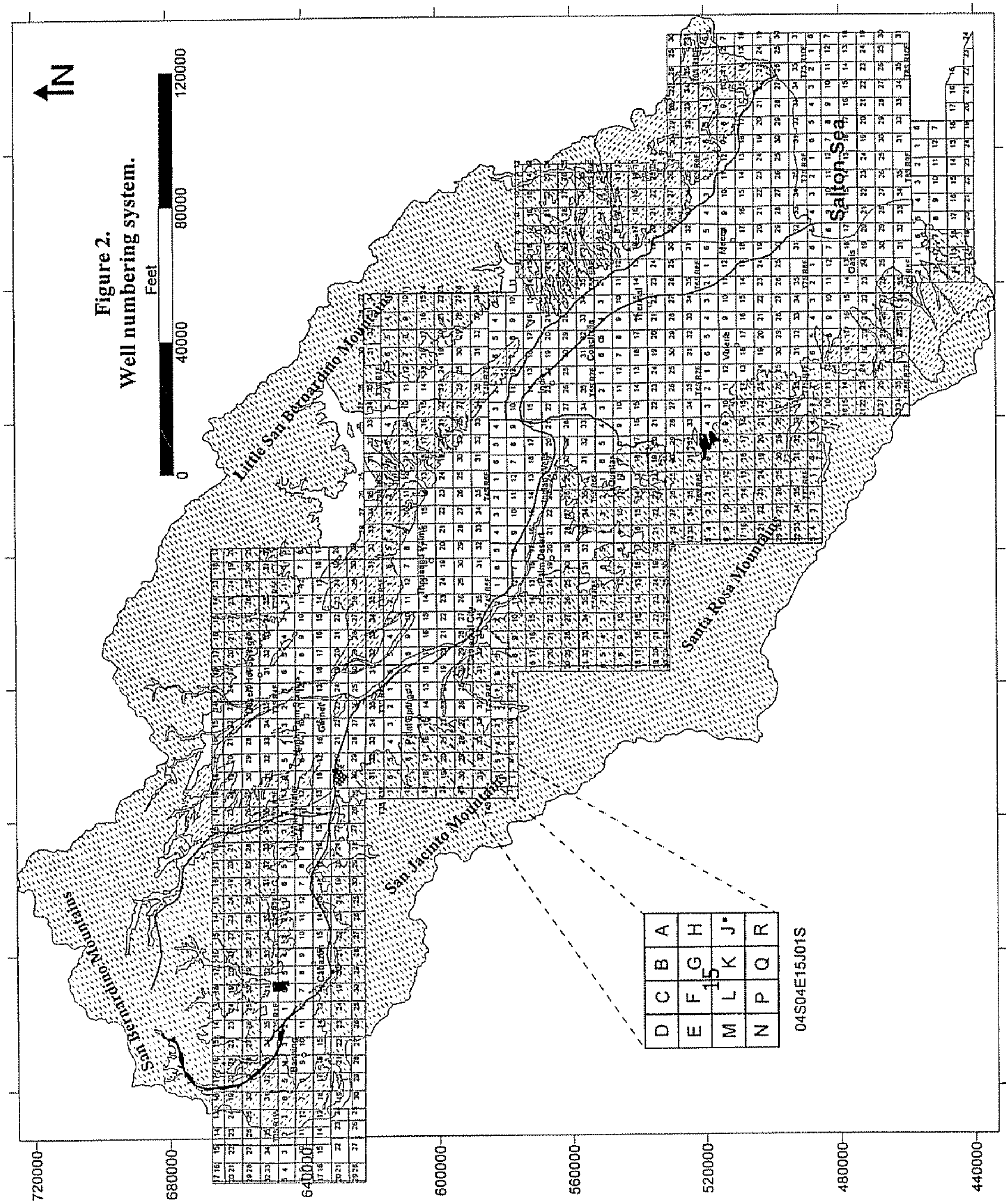


Figure 2.
Well numbering system.

In general, the Coachella Valley is part of a great structural trough that includes the Gulf of California. The northwest trending valley is bounded on the northeast by Pre-Tertiary metasedimentary and igneous rocks of the Little San Bernardino Mountains, to the southwest by Pre-Tertiary metamorphic and igneous rocks of the San Jacinto and Santa Rosa Mountains, to the northwest by the San Gorgonio Pass, and to the southeast by the Salton Sea. Thus, crystalline Pre-Tertiary igneous and metamorphic rocks comprise the mountain ranges and underlie the valley floor at substantial depths.

The basin is filled with thousands of feet of sedimentary materials of continental origin, with the exception of some Pliocene marine sediments. Thick deposits of Tertiary and Quaternary sediments overlie the crystalline bedrock. These sediments generally consist of coarse, alluvial fan deposits on the periphery of the basin, grading basinward into fine-grained deposits laid down in an alluvial plain and shallow lake environment (DWR, 1964).

The northwesterly trending San Andreas fault zone (Fig. 3) extends along the northeastern side of the basin. Large subparallel and branching faults of the San Andreas fault system are present in Coachella Valley, and act as partial barriers to groundwater flow. These faults include the San Andreas, Mission Creek, Banning, Garnet Hill, Indio Hills and Mecca Hills Faults (DWR, 1964).

2.4.2 Aquifer System

The groundwater basin generally coincides with the valley floor and is bounded by high mountains and faults (Fig. 3). The groundwater basin boundary, and its subdivision into subareas and subbasins, was determined by DWR (1964) on the basis of formation permeability, faults, well yields and water quality. Tyley (1974) further generalized the basin for modeling purposes in the upper valley. The mountains are composed of relatively impermeable rocks that impede the movement of groundwater. Unconsolidated Recent and late Pleistocene alluvial deposits form a complex aquifer system in Coachella Valley. The Pleistocene Ocotillo Conglomerate is the principal water-bearing unit and consists of poorly consolidated sandstones and conglomerates with lenticular interbeds of silts and clays. This unit reaches at least 2,400 ft in thickness (DWR, 1964). In the lower valley, the upper part of the Ocotillo Conglomerate consists primarily of 100 to 200 ft of lake-deposited materials of low permeability, which form a confining unit (or aquitard) above the main or lower aquifer. Figure 4 illustrates the regional hydrostratigraphy, and Figure 5 shows a generalized stratigraphic column in the lower valley.

The San Gorgonio Pass is an east-west trending, narrow valley approximately 15 miles long between the San Jacinto and San Bernardino Mountains that provides Coachella Valley access to the coastal plains to the west. A coarse sandy alluvial fill chiefly underlies the pass area. Drillers' logs indicated very coarse and poorly sorted materials with little or no fines present through most of the pass area; these materials are more than 1,000 ft thick (DWR, 1964).

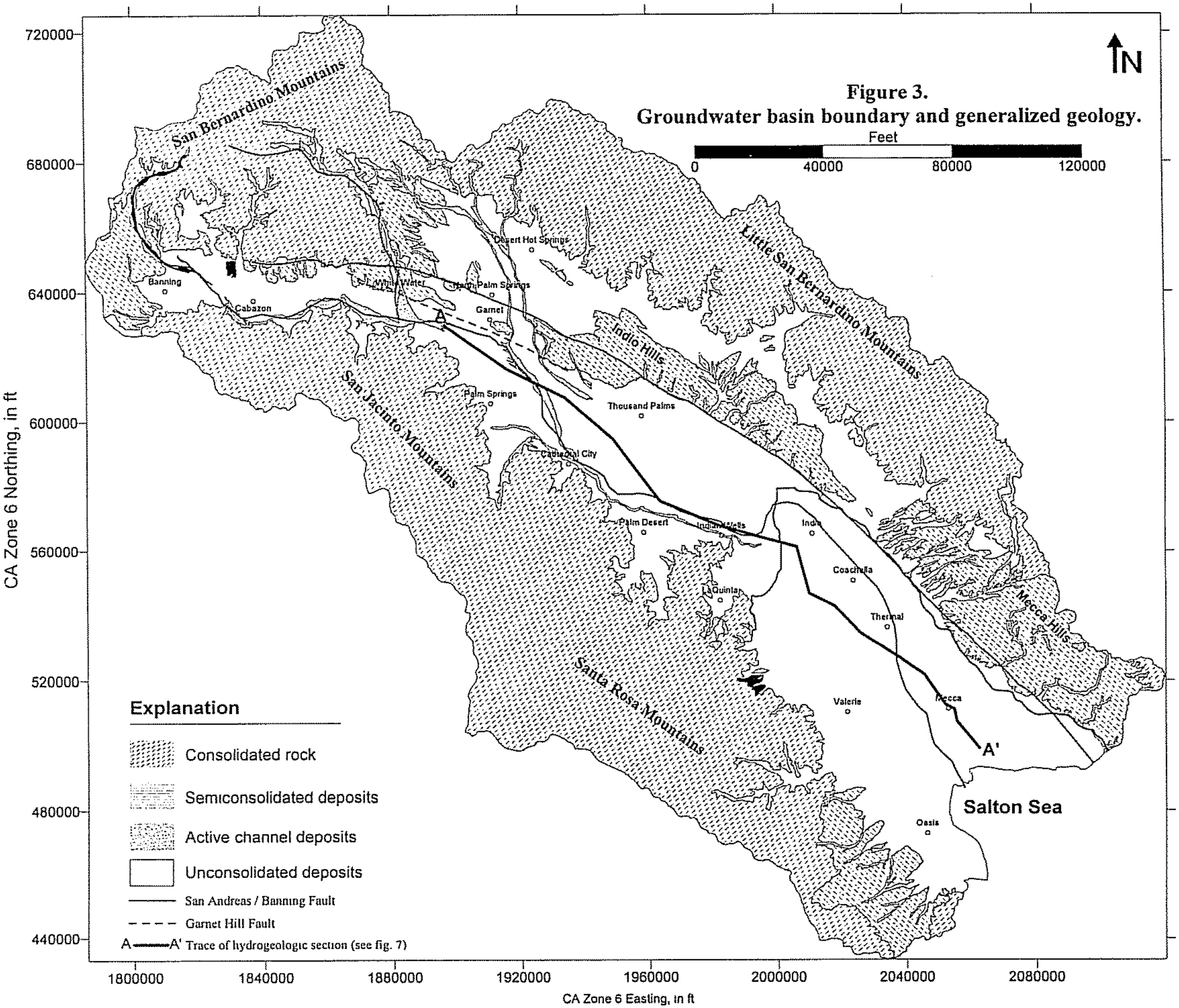


Figure 3.
Groundwater basin boundary and generalized geology.

Figure 4.
Schematic geologic section through Coachella Valley.

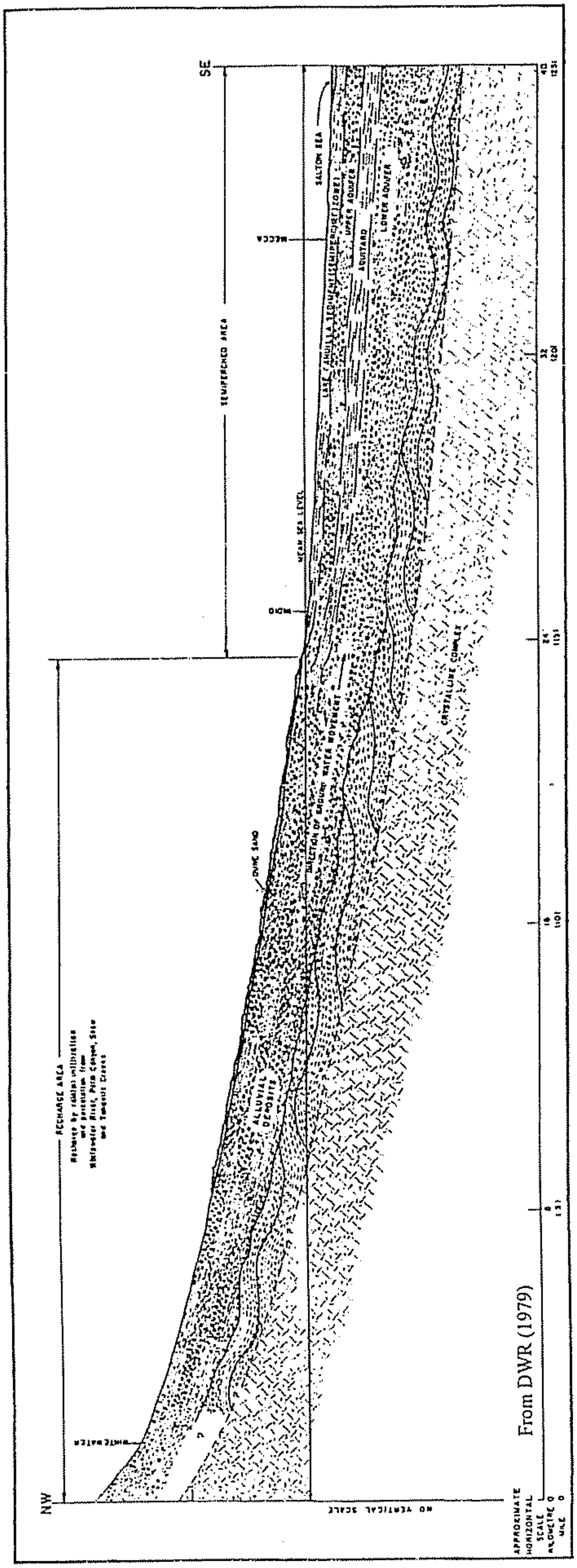
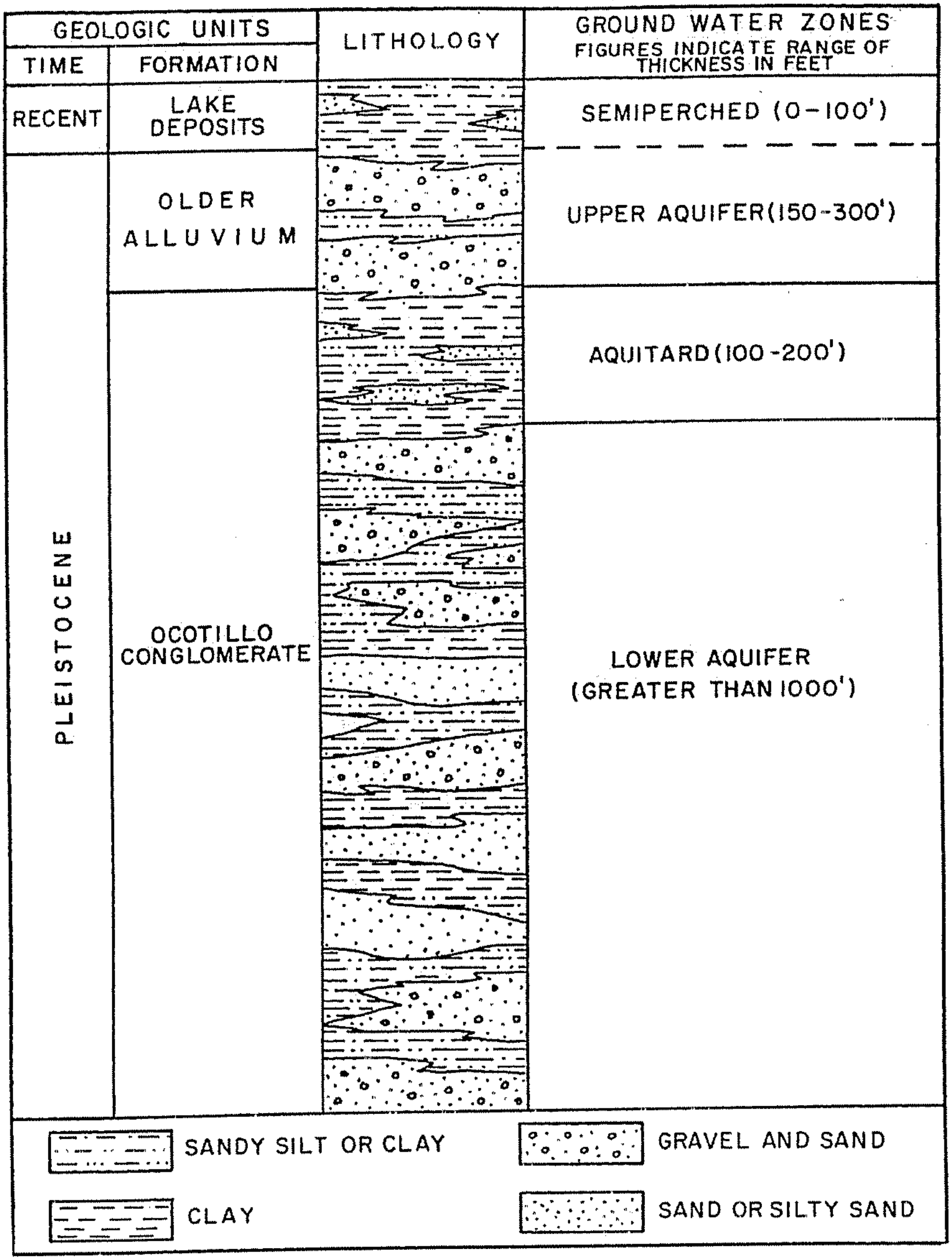


Figure 5.
Generalized stratigraphic column in lower Coachella Valley.



From DWR (1964)

Along the periphery of the entire valley, and in the upper valley from the San Gorgonio Pass to Cathedral City, are heterogeneous alluvial fan and stream wash deposits containing relatively small amounts of fine-grained materials. Thicknesses of the fan deposits commonly exceed 1,000 ft. Recent deposits, possibly 300 to 400 ft thick overlie the Ocotillo Conglomerate. In general, groundwater is unconfined, and the major sources of recharge to the aquifer are mountain-front recharge and streamflow infiltration, and subsurface inflow from San Gorgonio Pass.

Alluvial plain and lake deposits (interbedded sand, silts and clays) underlie the center of the valley from as far north as Cathedral City to the Salton Sea. A large area in the center of the upper valley between Cathedral City and Point Happy is underlain by Recent dune sand. Active channel deposits (sand, gravel and boulders) are found along the Whitewater River and its tributaries (Fig. 3). Unconfined groundwater occurs in the alluvial fans at the base of the Santa Rosa Mountains, while confined or semiconfined conditions occur in the central part of the valley. Sand and gravel bodies are discontinuous and clay beds are often not extensive; however, two aquifer zones separated by a zone of fine-grained materials were identified from well logs (DWR, 1964). Figure 6 shows the extent of the zone where multiple aquifers were found. In a later report, DWR (1979) investigators found they could not correlate the aquitard throughout the lower valley.

The present study found the geologic characterizations from DWR (1964; 1979) to be consistent with available electric and drillers log data; however, the data clearly show that the aquifers and aquitard in the multiple aquifer zones are complexly interbedded intervals of sand, gravel, silt and clay rather than distinct, coherent zones (Fig. 7). This is typical of the fluvial and alluvial fan depositional environments in which most of these sediments were deposited. Nevertheless, the conceptual model of an extensive confining unit of relatively low permeability (DWR, 1964) proved to be consistent with measured and model simulated water levels.

Southeast of Indio, Recent tight silts and clays up to 100 ft thick of the semiperched zone caps the upper aquifer. The low permeability of these materials retards deep percolation of irrigation water, causing drainage problems. Figure 8 shows the areal extent of the semiperched zone. No evidence has been found to suggest the semiperched zone is an actual perched aquifer; rather, conditions remain totally saturated below the semiperched aquifer.

Inflow to the aquifer system occurs as subsurface inflow and areal recharge. Subsurface inflow occurs from the San Gorgonio Pass and across the Banning Fault. Areal recharge includes streamflow infiltration, mountain-front recharge, irrigation return flow, sewage-effluent return flow, and artificial recharge. Streamflow infiltration and mountain-front recharge are the primary natural sources of water to the aquifer system.

The general direction of groundwater movement is southeastward toward the Salton Sea. Groundwater discharge from the aquifer system occurs from wells, drains, evapotranspiration from native vegetation, and as subsurface outflow to the Salton Sea.

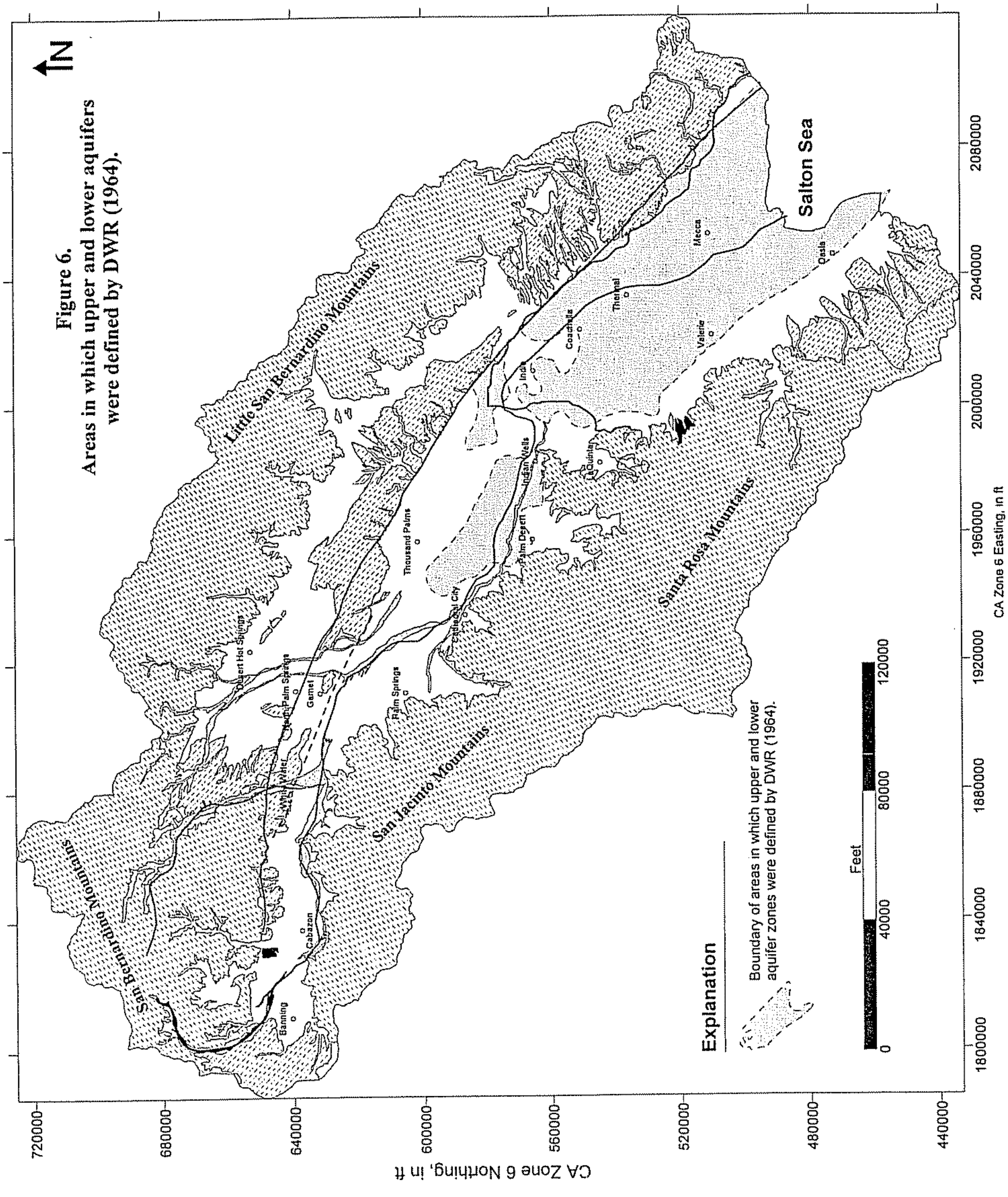


Figure 6. Areas in which upper and lower aquifers were defined by DWR (1964).

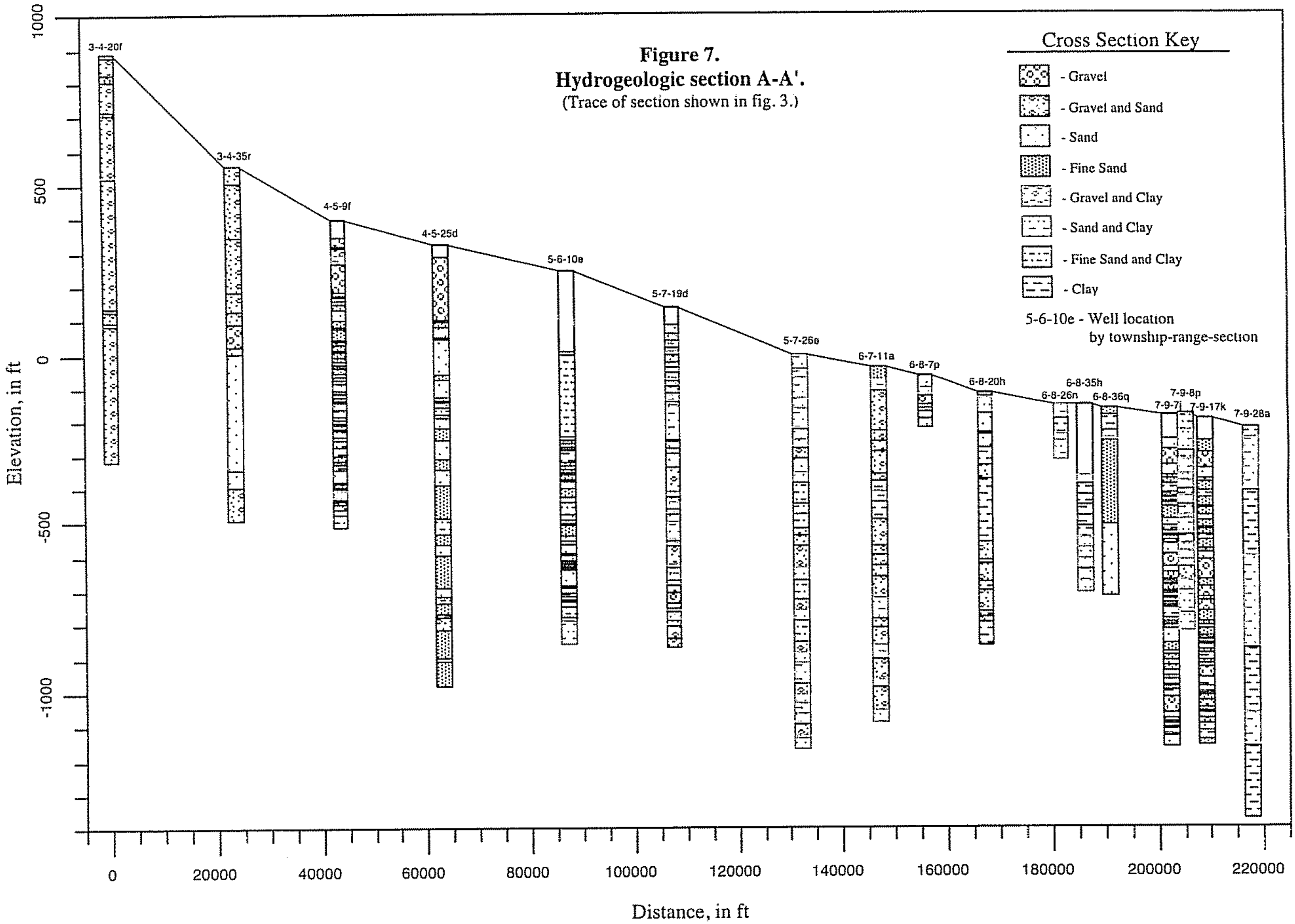


Figure 7.
Hydrogeologic section A-A'.
(Trace of section shown in fig. 3.)

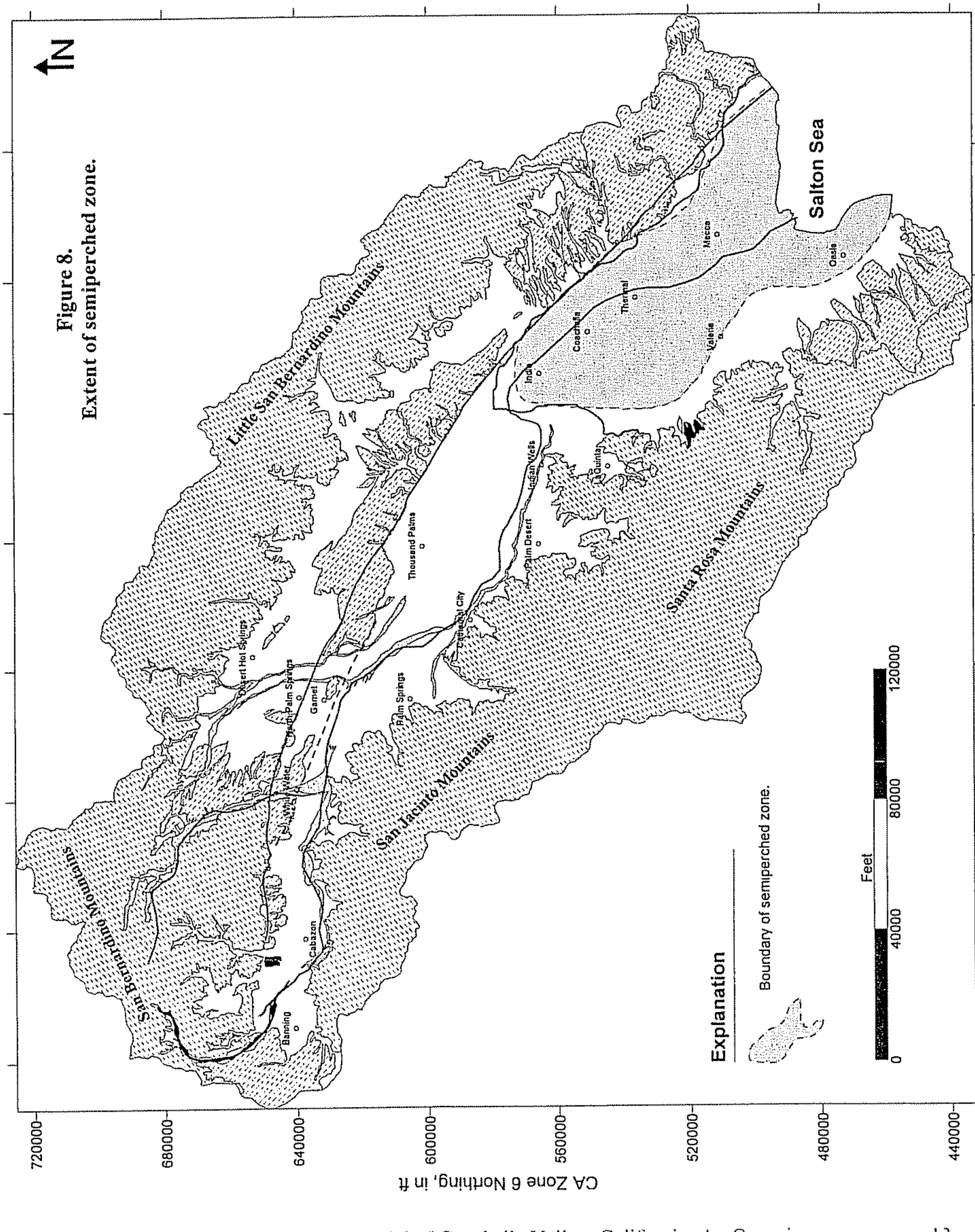


Figure 8.
Extent of semiperched zone.

The direction of vertical groundwater flow in the lower valley has changed over time due to development. DWR (1979, Plate 5) mapped the extent of flowing artesian conditions in 1905, 1946, and 1969. Artesian conditions were extensive in 1905, roughly equivalent to the area of the semiperched zone. By 1946, due to significant groundwater pumping from the lower aquifer, the area of artesian pressures had shrunk to less than half its 1905 extent. Since 1949, imported Colorado River water has been the principal irrigation water supply in the lower valley, and with reductions in agricultural pumpage, groundwater levels increased from 1950-75. Consequently, the extent of artesian conditions in 1969 had increased almost to 1905 conditions. However, since 1975 water levels have again been declining in the lower valley and the area of artesian conditions has declined significantly from its 1969 extent. Analysis of water level data suggests that the direction of vertical groundwater movement in the center of the lower valley has shifted from primarily upward in the early part of the century, to downward from the 1930's to the early 1950's, then upward again from the late 1950's through the mid-1970's, and mostly downward since.

Transmissive properties of the aquifer system are greatest in the upper alluvium along the Whitewater River channel in the upper valley, and within the alluvial fans along the southwestern boundary of the valley. Thus, except within Recent stream channel deposits, transmissivities are higher on the southwest margins of the basin grading to lower values in the center. Also, permeabilities tend to decrease southeastward toward the Salton Sea; well logs confirm the existence of low permeability silts and clays near, and presumably beneath, the Salton Sea. Additionally, low permeability materials characterize the semiperched zone and aquitard units in the lower valley.

Storage coefficients of the aquifer system are much greater in the upper unconfined alluvium than in the deeper confined units. The model computes the volume of water taken into and released from storage in the system with changes in hydraulic head.

2.5 Groundwater Development

A brief history of groundwater development in Coachella Valley through 1996 is presented here to document the significant natural events and human influences affecting groundwater in the basin. A review of these conditions aids in understanding the resulting groundwater levels in the basin and, in turn, performance of the model in the simulation of historical trends. Every major change in groundwater levels and flows computed by the model can be attributed directly to historical events in the basin.

The modern history of the Coachella Valley began with the completion of the Southern Pacific railroad in 1879 (DWR, 1964). The railroad used artesian wells, and farmland was put under production as settlement of the area began. Irrigation development did not advance rapidly because of the prohibitive cost of drilling and operating wells. But the development of economical well-drilling methods and pumping machinery around 1900 lessened the costs, and by 1906, 400 wells had been installed; by 1916, the irrigated land in Coachella Valley increased to 7,000 acres.

The Salton Sea was formed from 1904 to 1907 as a result of diversion of Colorado River water for irrigation in Imperial Valley, and the concurrent occurrence of floods in the Colorado River (Hely et. al, 1966). The present day Sea has been sustained chiefly by drainage from irrigated lands in Imperial Valley. Figure 9 is a chart of Salton Sea water surface elevations showing how the present sea level has evolved since 1904.

Increasingly, more agricultural land was developed and the limitations of the natural water supply became evident as groundwater levels in the valley declined. In 1918, CVWD was formed to protect, conserve, and supplement Coachella Valley's water supplies. In 1919, CVWD built recharge ponds near Windy Point to capture and percolate runoff from the Whitewater River.

CVWD early recognized the need for additional water beyond the natural replenishment to support the continued development of the varied economies in the valley. In 1934, CVWD contracted to build the Coachella Branch of the All-American Canal to bring Colorado River water to Coachella Valley. Construction of the Coachella Canal began in 1938 when there were about 14,000 acres of land under irrigation, and was completed in 1948 when there were about 23,000 acres under irrigation. By then, increased pumping of groundwater for municipal and recreational use in the upper valley, and for agricultural use in the lower valley, had led to widespread water-level declines. Since 1948, irrigated agriculture has increased rapidly; today there are over 60,000 acres being farmed (Fig. 10).

With the completion of the Coachella Canal in 1948, imported water from the Colorado River began to supplement groundwater use for agriculture in the lower valley, and concurrent reductions in groundwater pumpage helped to alleviate the overdraft. As shown on Figure 11, annual deliveries of Colorado River water via the Coachella Canal rose from about 30,000 acre-ft per year in 1949 to over 300,000 acre-ft per year in 1958; also, between 1958 and 1975, Coachella Canal deliveries averaged about 325,000 acre-ft per year, reaching a high value of nearly 370,000 acre-ft in 1975. However, since the late 1970's, the demand for water in the lower valley has increased relative to the deliveries of imported surface water. As a result, groundwater levels have again been declining in the lower valley, due to decreasing annual deliveries of water from the Coachella Canal, and concomitant increases in groundwater production necessary to meet the demand. In fact, from 1976 to 1996, annual canal deliveries declined and averaged less than 300,000 acre-ft per year (Fig. 11).

Figure 12 shows a typical hydrograph for a well in the lower valley. Note that water levels declined from the late 1920's until groundwater pumpage decreased when Coachella Canal water became available in 1949. Higher water levels, from the late 1950's to the late 1970's resulted from a combination of decreased pumpage and the use of imported water as the primary source for irrigation. Water levels have declined since the 1970's due to declining deliveries of imported water for irrigation, and associated increasing rates of groundwater pumpage.

Beginning in 1950 and largely completed by 1975, CVWD installed and maintains a system of 166 miles of pipe and 21 miles of open drains that serve as a drainage network for irrigated lands. Subsurface tile drains intercept high groundwater and irrigation return flows while controlling soil salinity. Most of the drainage empties into the CVSC and ultimately to the Salton Sea. Figure 13 charts the total acreage served by drains over time. Figure 14 charts the total annual measured agricultural drain flows.

Figure 9.
Historic surface elevation of Salton Sea.

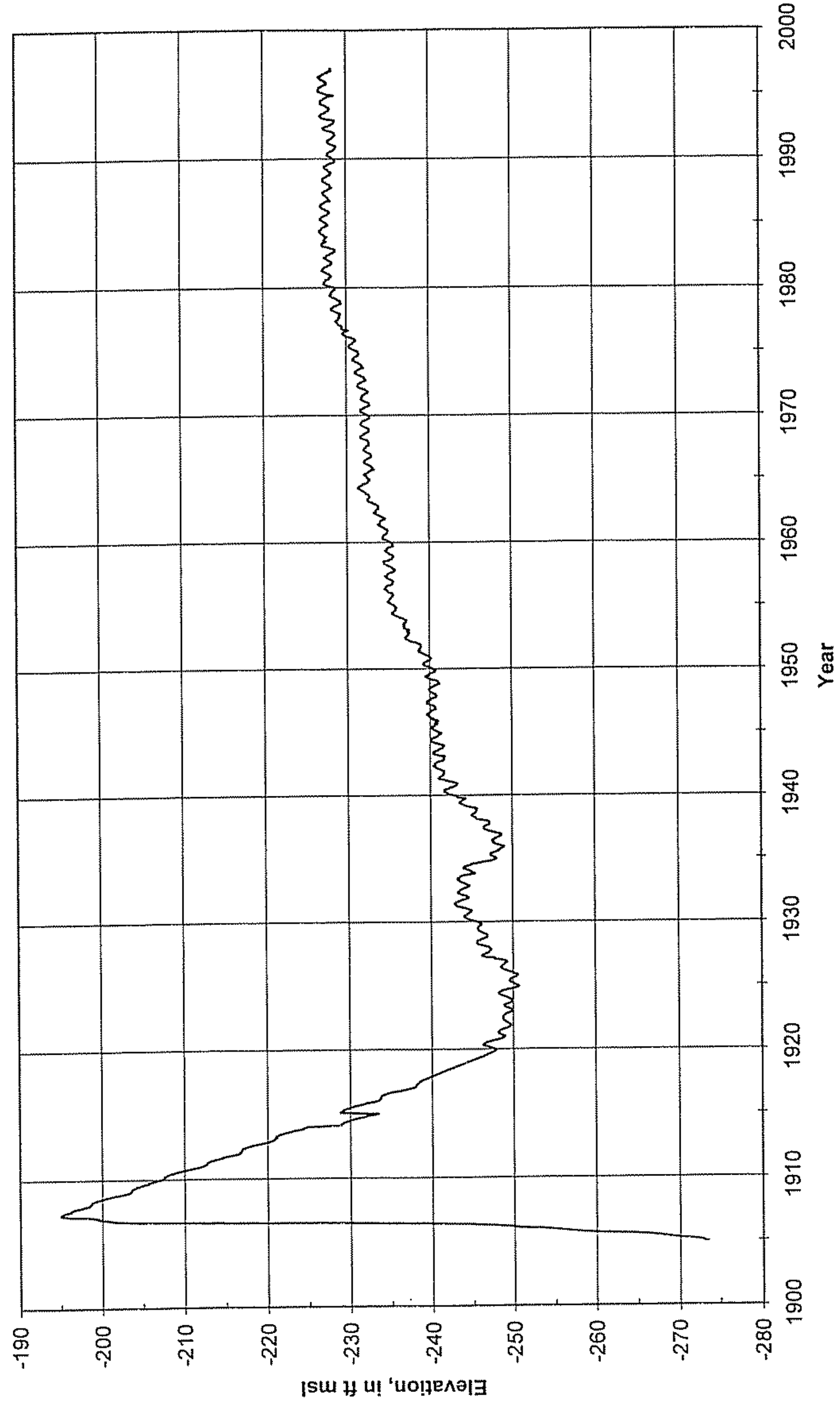


Figure 10.
Agricultural acreage in Coachella Valley.

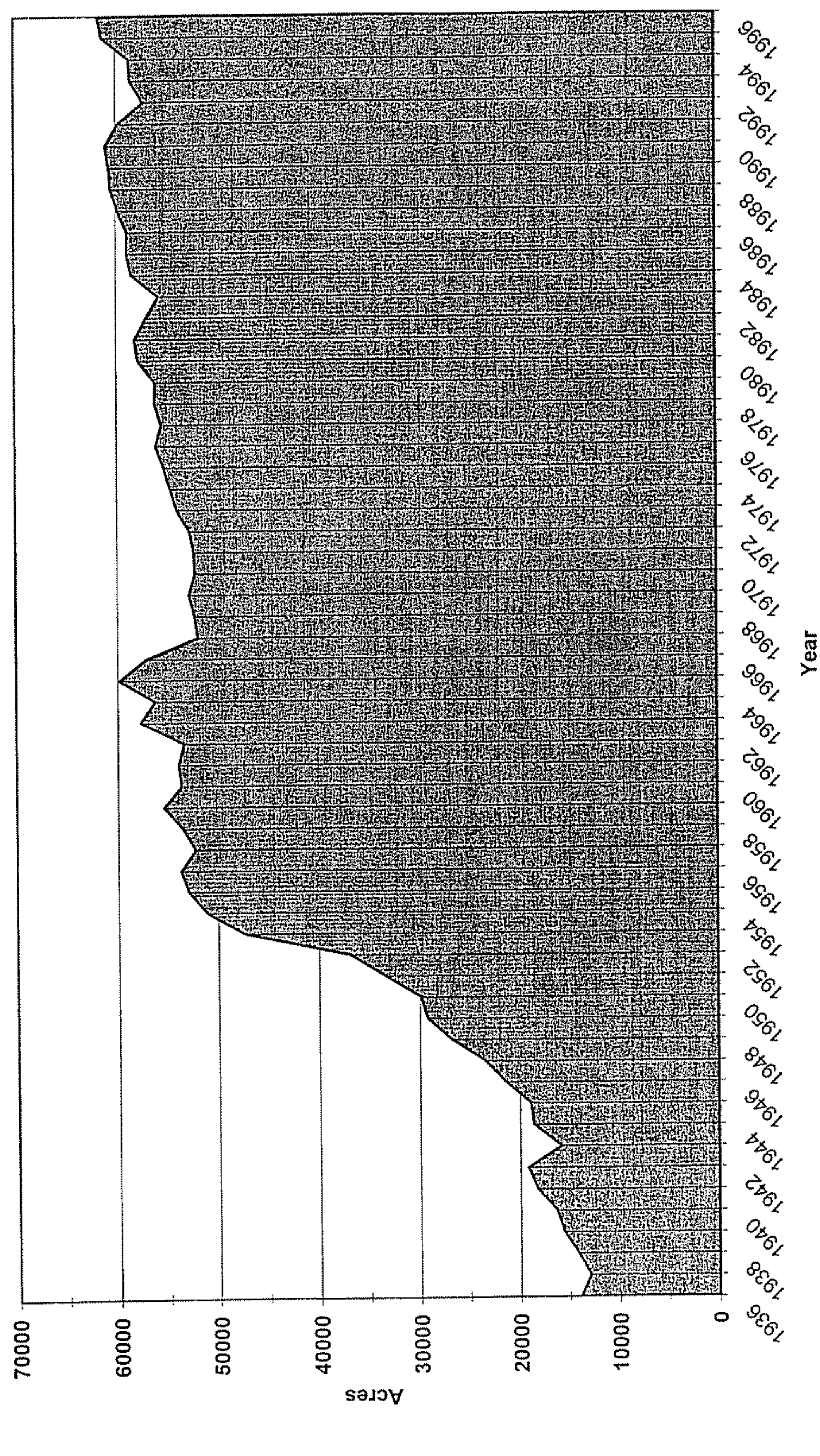


Figure 11.
Total annual farm deliveries from Coachella Canal.

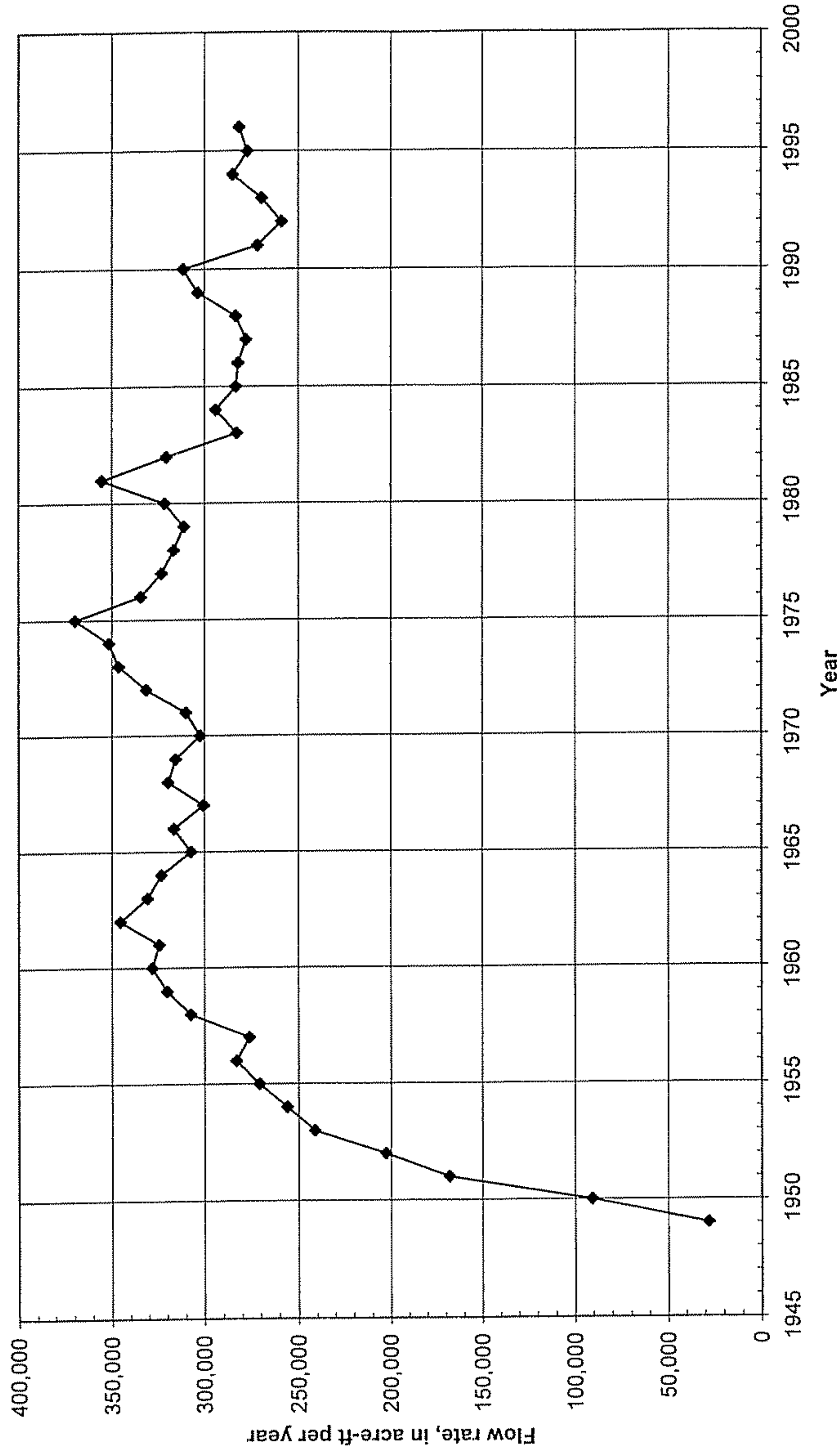


Figure 12.
Hydrograph of lower valley well 06S07E22B01S.

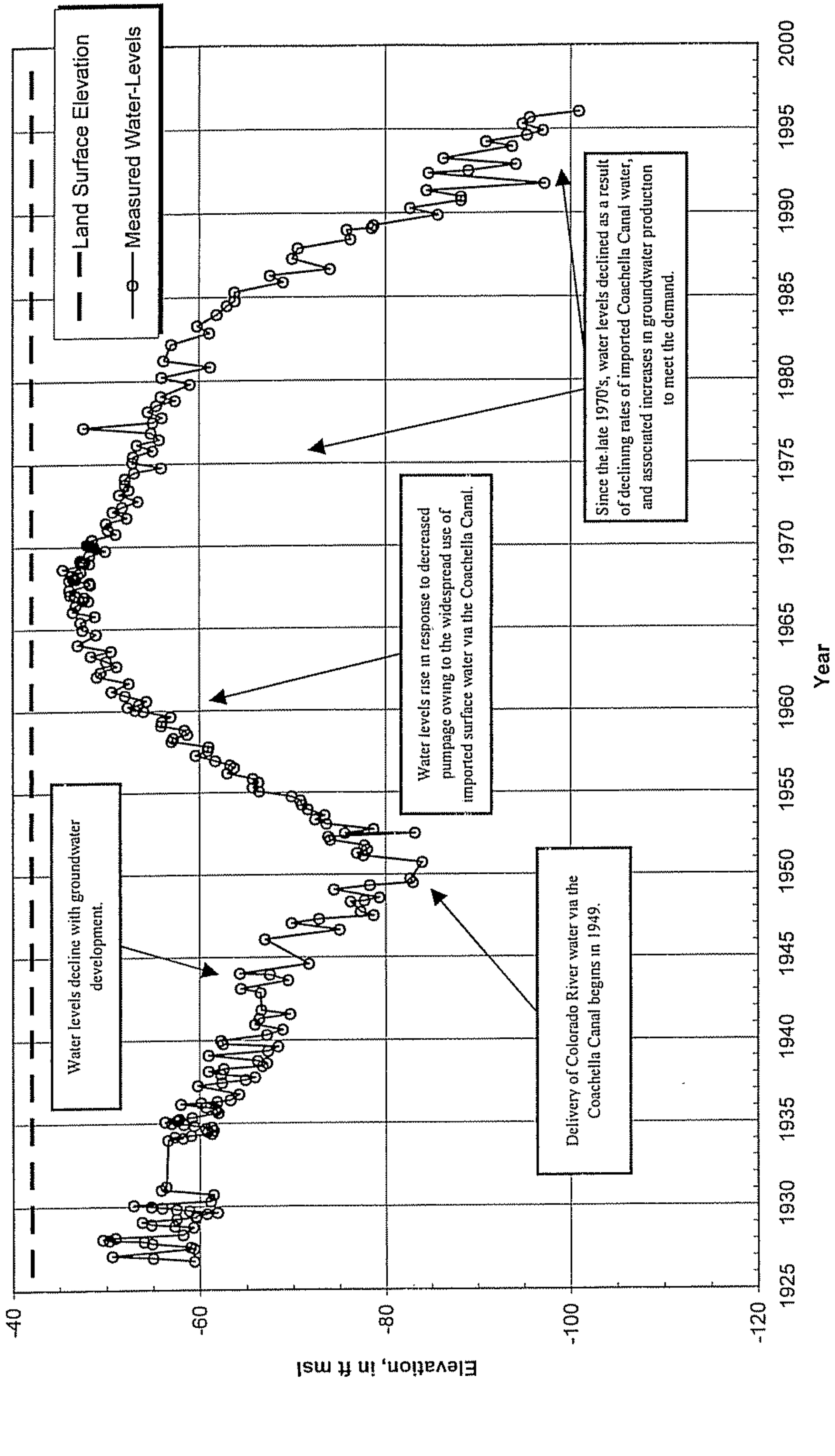


Figure 13.
Total farm acreage served by drains.

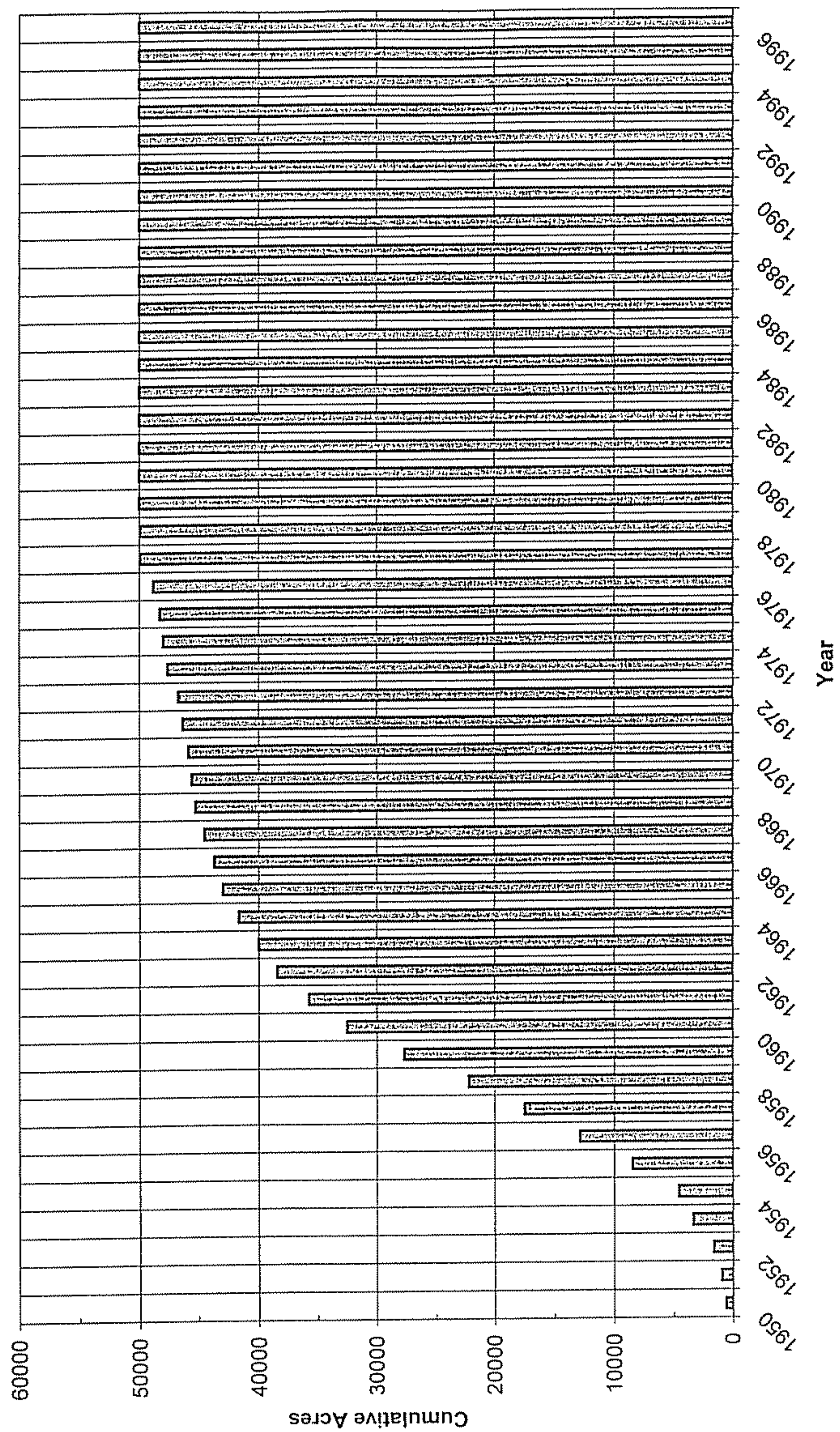
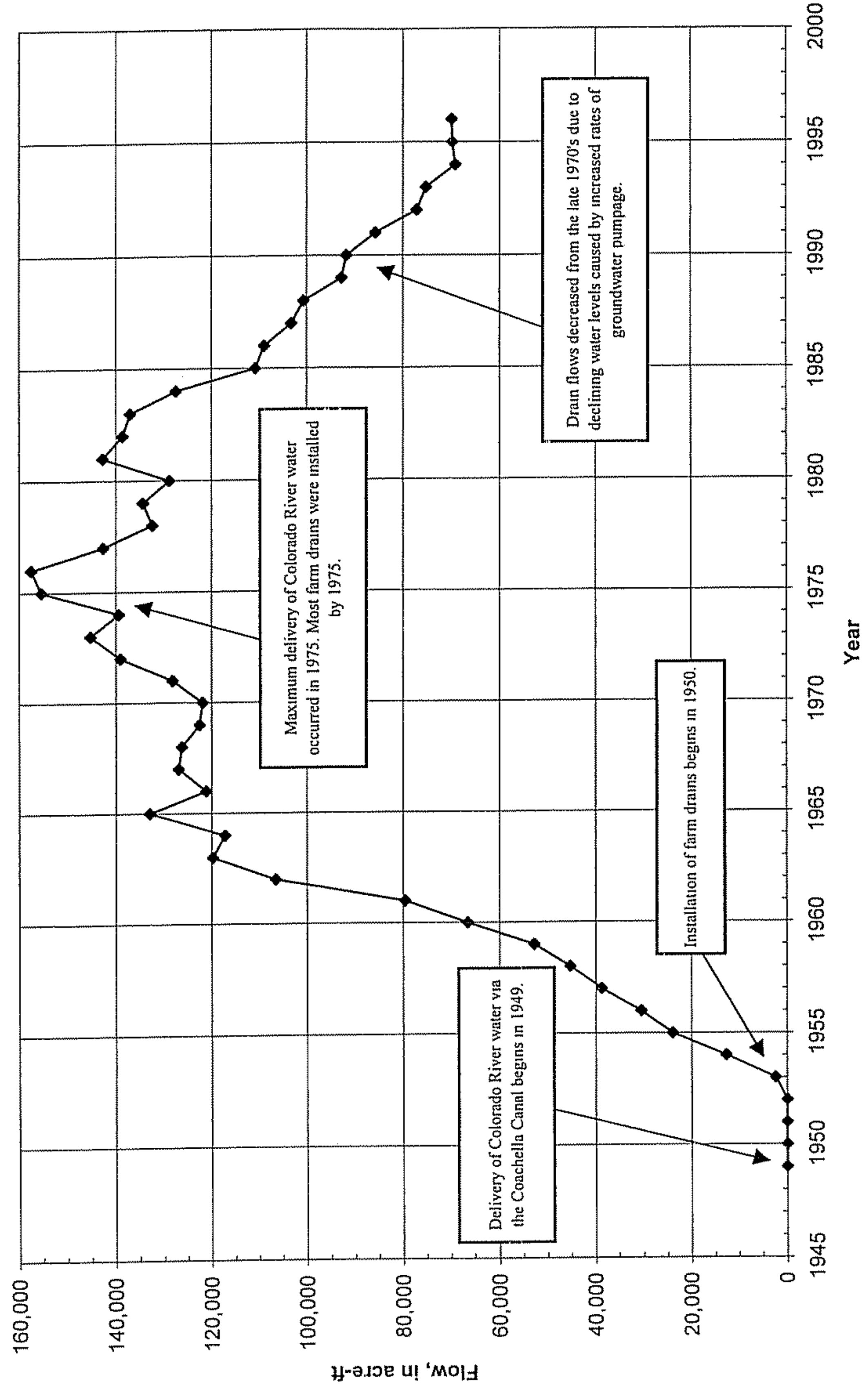


Figure 14.
Total annual agricultural drain flows.



In 1963, CVWD and Desert Water Agency (DWA) entered contracts with the state for entitlements to State Water Project (SWP) water. CVWD and DWA entered an exchange agreement with Metropolitan Water District of Southern California (Metropolitan) to trade their SWP entitlement for the same amount of Colorado River water (from Metropolitan's Colorado River Aqueduct, which crosses Coachella Valley near White Water). In 1972, CVWD expanded the percolation ponds near Windy Point, and in 1973, CVWD and DWA began to receive these exchange waters. Figure 15 shows the total annual diversions from the Colorado River Aqueduct into the Whitewater River for artificial recharge at Windy Point.

By 1974, groundwater levels had declined from 60 to over 100 ft below their 1936 levels in the upper valley. Groundwater pumpage has continued to increase in the upper valley; however, above average precipitation in the late 1970's, early 1980's and mid-1990's, combined with significant artificial recharge in the 1980's, temporarily slowed the rate of water-level declines. Nevertheless, water levels are presently declining in the upper valley. Figure 16 shows a characteristic hydrograph for a well in the upper valley. Note that water levels declined from the beginning period of measurement until the late 1970's and early 1980's when significant precipitation and artificial recharge occurred in the upper valley.

3 MODEL CONSTRUCTION

The model is implemented with the computer code MODFLOW (McDonald and Harbaugh, 1988), which simulates groundwater flow in three dimensions using a block-centered finite-difference approach. The code conforms to modern theory and standard practice for solving the equations of groundwater motion and provides an excellent means of representing the complex aquifer system in Coachella Valley.

The area covered by the groundwater model is shown on Figure 17. The upstream and downstream ends of the model correspond to the San Gorgonio Pass area and Salton Sea, respectively. The southwest flank of the model represents the interface between the unconsolidated sedimentary fill and consolidated to semi-consolidated rocks of the San Jacinto and Santa Rosa Mountains. The northeast flank of the model represents the interface between the unconsolidated sedimentary fill and consolidated to semi-consolidated rocks of the Little San Bernardino Mountains, Indio Hills, and Mecca Hills. Most of the ephemeral stream flow into the basin originates along the southwest flank. Note that the San Gorgonio Pass, Mission Creek and Desert Hot Springs subbasins are not explicitly modeled; subsurface outflow from these subbasins into the main basin is included in the boundary conditions at the Pass, and along the Banning and San Andreas faults.

3.1 Finite-Difference Mesh

The model consists of a three-dimensional, finite-difference mesh of blocks called cells, the locations of which are described in terms of the 270 rows, 86 columns and 4 layers in the mesh. At the center of each cell there is a point called a node at which head is calculated. The model has a node spacing of 1,000 ft in the x-y plane, and variable vertical node spacing representing variable thicknesses of the corresponding aquifer or aquitard intervals. The mesh is oriented along the length of the valley, coinciding with the principal direction of regional groundwater flow.

Figure 15.
Total annual water diverted from Colorado River Aqueduct to Whitewater River.

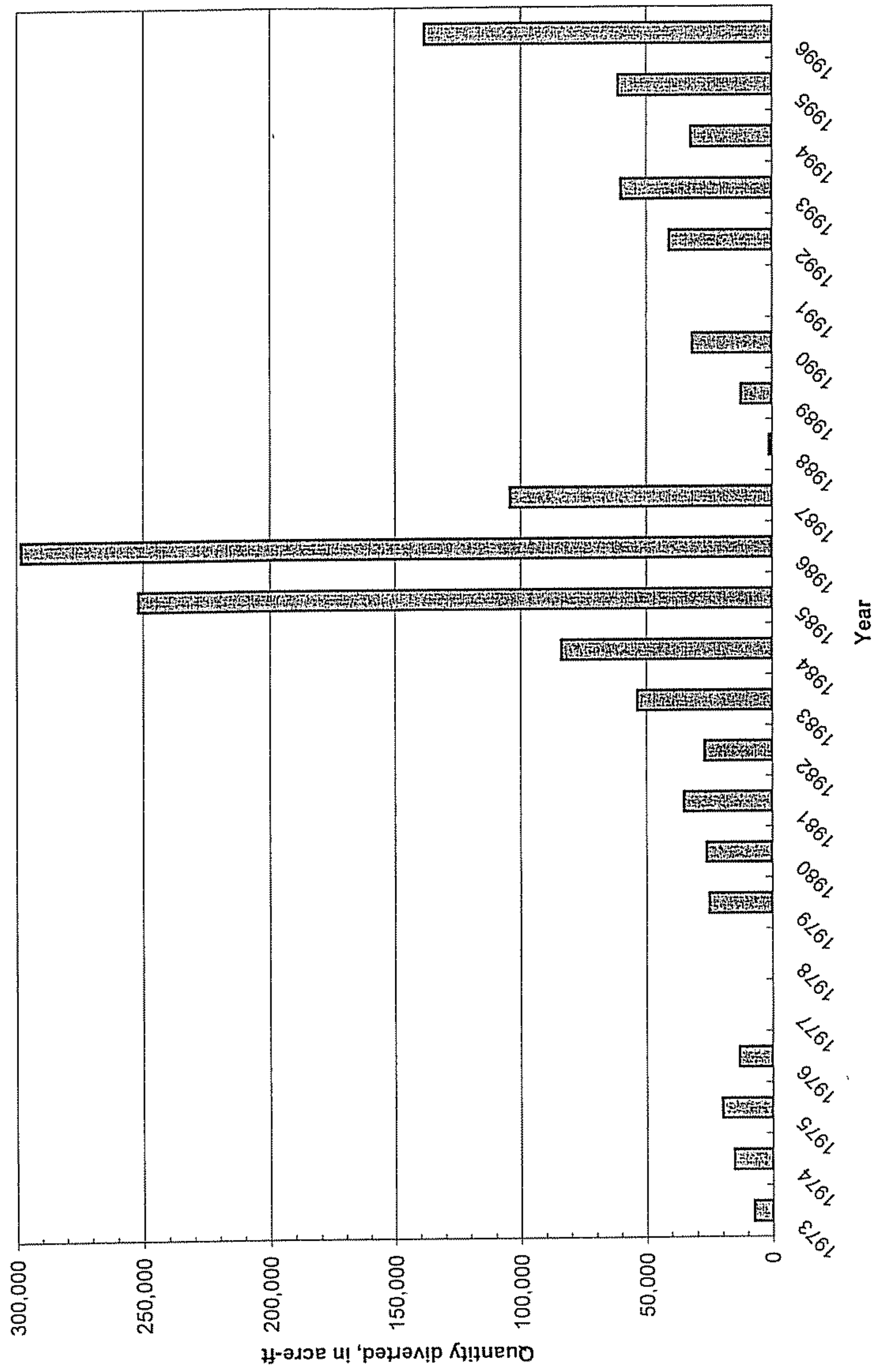
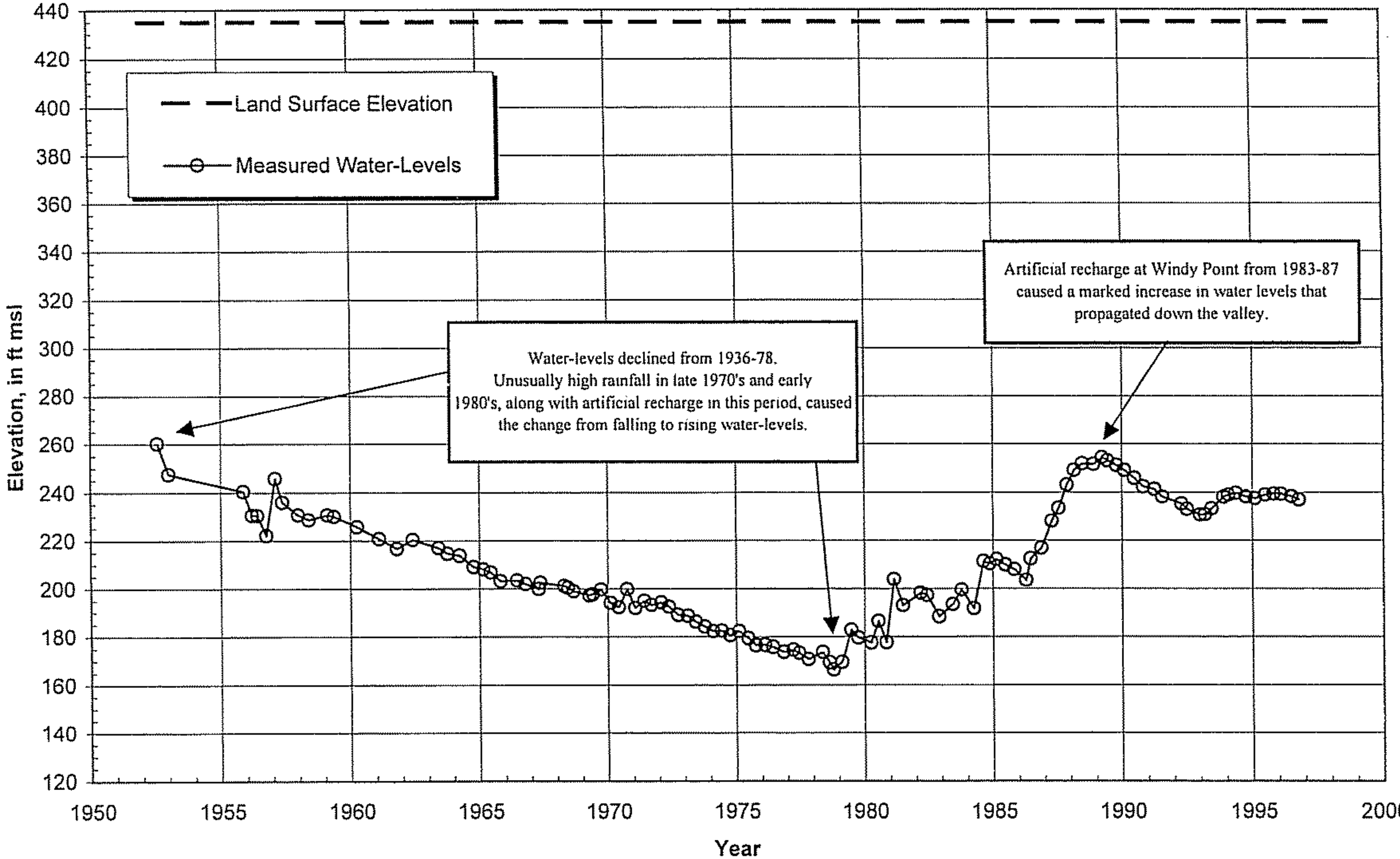


Figure 16.
Hydrograph of upper valley well 04S04E15J01S.



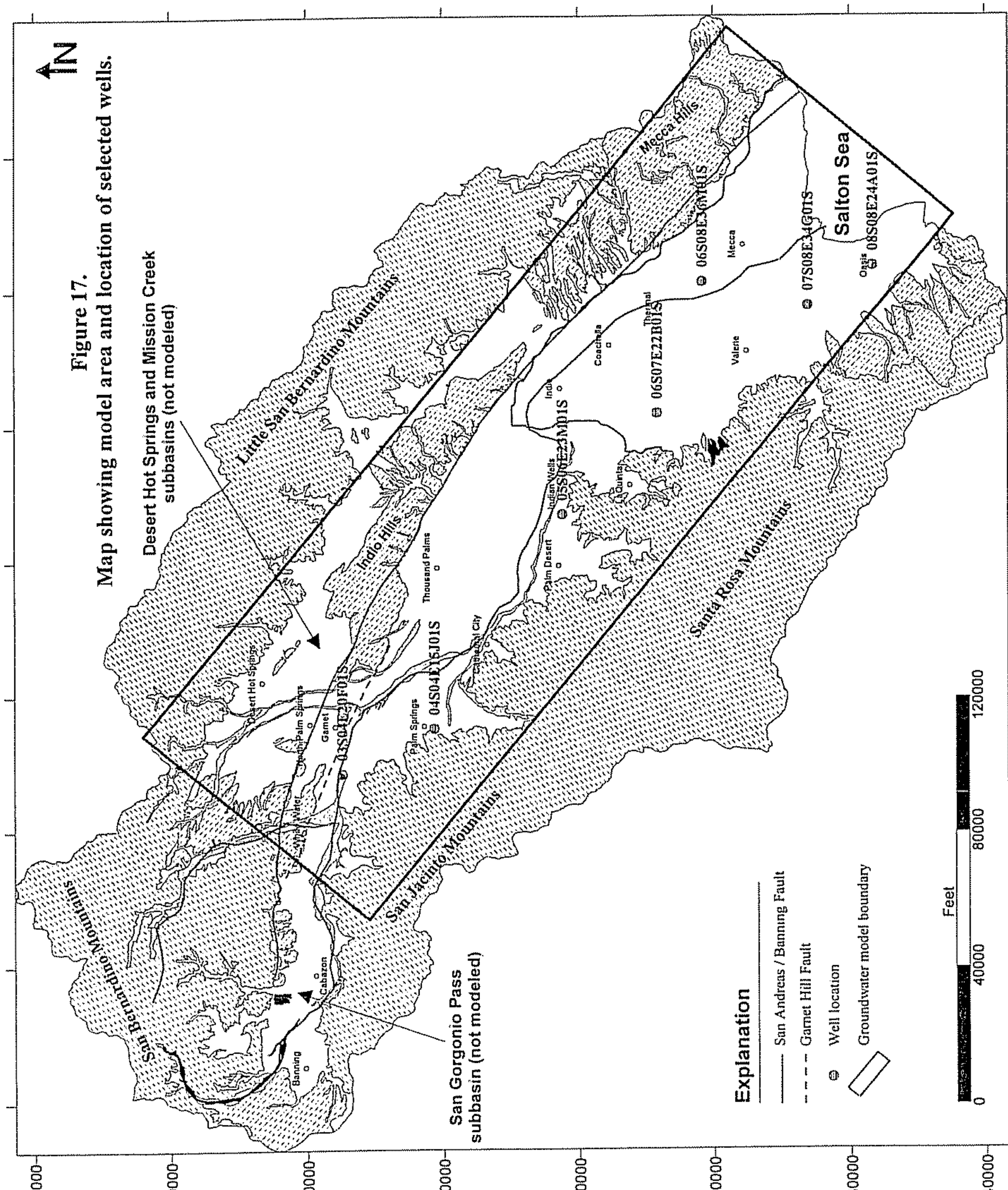


Figure 17.
Map showing model area and location of selected wells.

Figure 18 shows the horizontal layout of the mesh for layer 1, the uppermost layer. The shaded cells around the perimeter are inactive (no-flow) cells and define the x-y plane geometry of the flow region. The inactive cells lie in areas of low-permeability, consolidated to semiconsolidated rocks or in subbasins of Coachella Valley that are substantially isolated from the main basin by faults (see Tyley, 1974). The 48,396 active cells represent unconfined and confined aquifer systems in the Recent and Pleistocene sedimentary fill.

Figure 19 shows a cross-section of the groundwater model mesh along the length of the valley, roughly through its center; Figure 20 shows a section that crosses the valley near the city of Coachella. Top and bottom elevations of the four model layers are placed mainly to represent the multiple aquifer zones present in the lower valley and were derived from USGS digital elevation models (DEM), and hydrogeologic characterizations from DWR (1964; 1979).

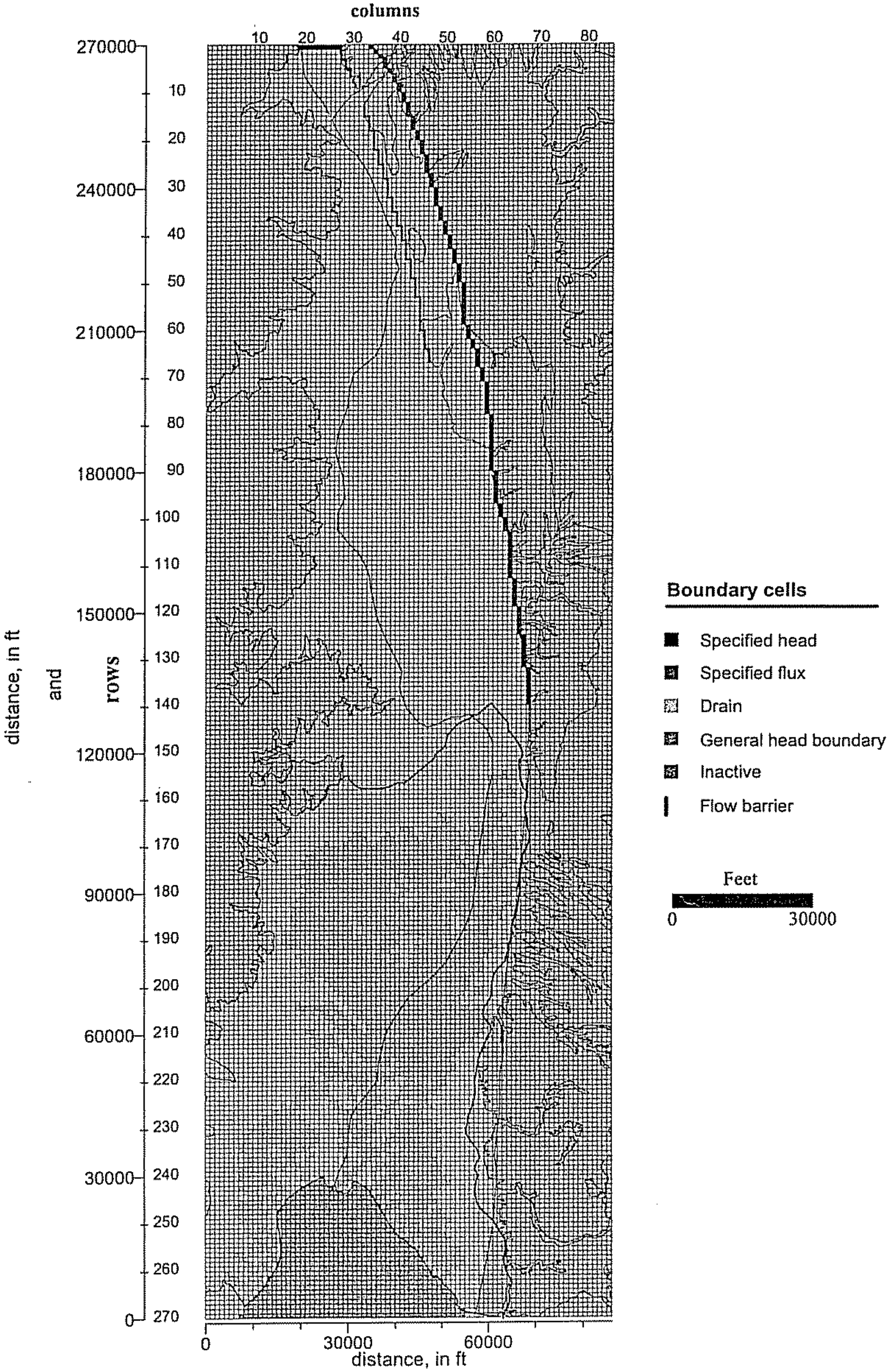
In the areas containing multiple aquifers (Fig. 6), layer 4 represents the lower aquifer, layer 3 represents an aquitard zone, layer 2 represents an upper aquifer, and layer 1 represents the semiperched zone (Fig. 8) in the lower valley and a shallow aquifer interval elsewhere. Near the southwest margin, total thickness of the layers slightly thins toward the San Jacinto and Santa Rosa Mountain front, where thickness of the sedimentary fill decreases. Outside the multiple aquifer zones, the four layers have no particular geologic significance but allow computation of vertical flow components in areas like the Whitewater River spreading ponds. No laterally extensive confining beds were found to exist outside the multiple aquifer zones. All the pumpage in the model comes from layers 4 and 2.

3.2 Boundary Conditions

Boundary conditions are used anywhere in the model domain to account for water entering or leaving that domain. Boundary conditions account for sources of water such as recharge ponds and subsurface inflow from adjacent basins, and wells and drains where groundwater discharges from the flow system. Model input data describing each set of boundary conditions were developed for the 51 stress periods that define conditions from 1936-96.

The active area of the model is bounded by the San Gorgonio Pass up slope (northwest) and the Salton Sea down slope (southeast), the San Jacinto and Santa Rosa Mountains and associated canyons along the southwest margin, and the Banning and San Andreas faults along the northeast margin. The base of the model represents the depth to which fresh water actively circulates. In the upper valley, the thickness of the active flow system is approximately 1,000 ft, based on observed decreasing resistivity with depth in geophysical logs and on maximum well depths (Reichard and Meadows, 1992). In the lower valley, thickness of the active flow system ranges from 1,000 ft to over 1,500 ft based on well logs and geologic characterizations from DWR (1964). The upper boundary of the flow system is the water table; processes affecting this boundary include recharge, drains, and evapotranspiration from natural vegetation.

Figure 18.
Model mesh and boundaries in uppermost layer.



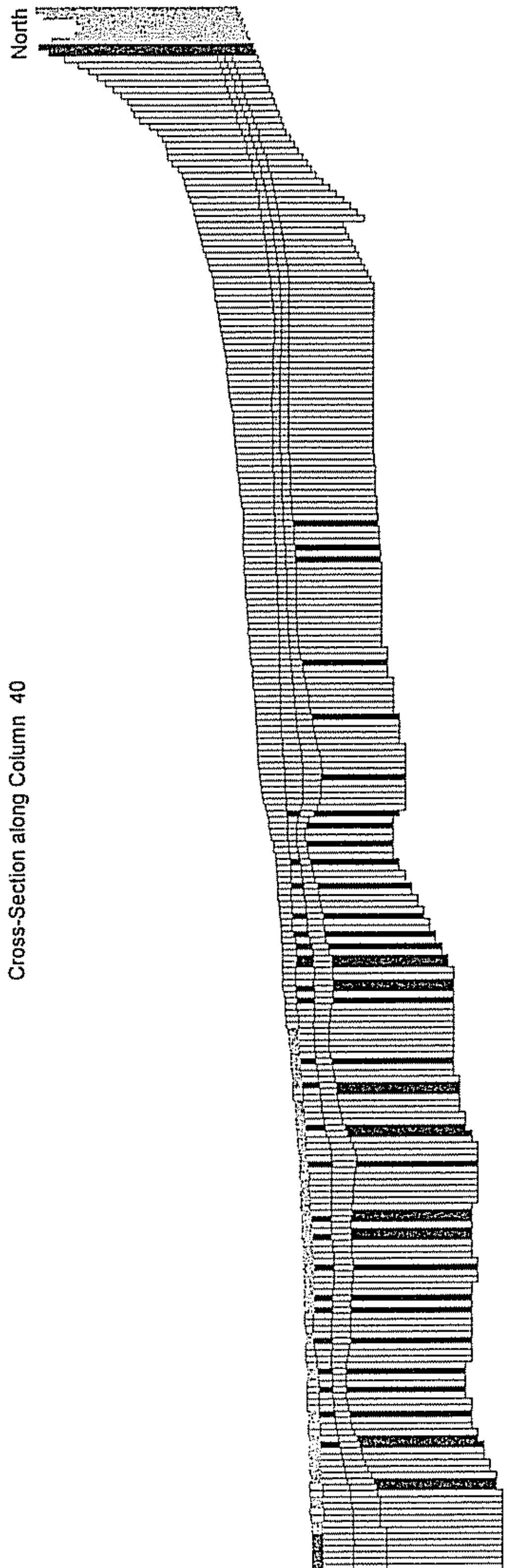


Figure 19.
Cross-section of model mesh along length of valley.

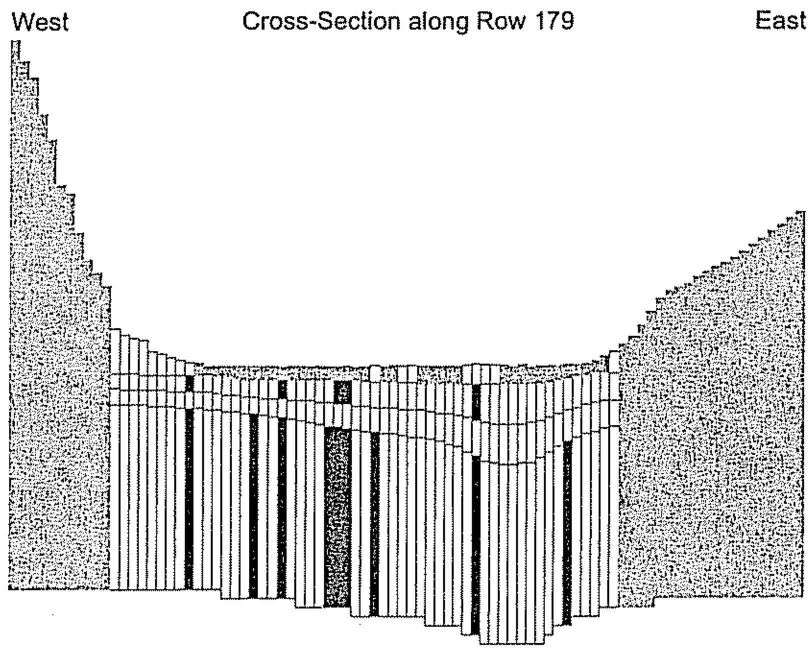


Figure 20.
Cross-section of model grid near Coachella. Vertical Exaggeration: 20x

Brief descriptions of the model boundary conditions and the methods used to estimate the boundary heads and fluxes are discussed in this section. Some boundary conditions represent flows that are input to the model, such as pumpage and recharge. Others, such as drains, evapotranspiration, and the Salton Sea boundary, are head-dependent boundaries where flows are computed by MODFLOW.

3.2.1 Natural Recharge

Recharge to the groundwater system from natural sources includes precipitation on the valley floor, infiltration of runoff from precipitation in the mountains, and inflows from adjacent groundwater basins.

3.2.1.1 Inflow from San Gorgonio Pass Area

The San Gorgonio Pass subbasin (DWR, 1964) is located northwest of the valley proper; groundwater flows from the subbasin into the model area across a buried bedrock ridge about one mile west of the junction of Interstate 10 and State Highway 111. Drainage within the pass area is tributary to Coachella Valley via the San Gorgonio River that enters the Whitewater River channel above Windy Point. However, there are no data available on streamflow in the San Gorgonio River near Windy Point.

A time-variant specified head boundary condition was used to model inflow from the San Gorgonio Pass for the period 1936-96. Measured groundwater levels in the vicinity of the boundary were used to specify the time-dependent head.

3.2.1.2 Inflow Across Banning and San Andreas Faults

Subsurface inflow occurs across the Banning and San Andreas faults, which form the northeasterly boundary of the main groundwater basin. These faults are segments of the San Andreas Fault zone, which consists of several parallel faults, some of which diverge from the main fault system.

The Banning Fault extends from the west end of San Gorgonio Pass easterly and then curves southeasterly along the Indio Hills. The Banning Fault is considered an effective, but imperfect, barrier to groundwater movement based on significant groundwater level and quality differences across the fault. In the portion extending southeasterly from the San Bernardino Mountains to the Indio Hills, the Banning Fault separates the Mission Creek subbasin to the northeast from the Garnet Hill subbasin on the southwest. Groundwater level differences across the Banning Fault in this area are on the order of 200-250 ft. Along the Indio Hills, springs, cienegas and dense vegetation in canyon oases stem from the barrier effects of the fault. Tyley (1974) estimated flow across the Banning Fault into the Garnet Hill Subbasin to be 2,000 acre-ft per year. This value was assigned uniformly to specified-flux cells along the fault in the current model.

The Banning Fault merges with the Mission Creek Fault in the central Indio Hills. From this point southeasterly, the fault is generally referred to as the San Andreas Fault. The presence of palm tree oases along the southwest flank of the Indio Hills and abrupt changes in vegetation southeast of the Indio Hills are indicative of the effectiveness of this zone as a barrier to groundwater flow (DWR, 1964). Additionally, contour maps of groundwater elevations in the lower valley over time generally show equipotential lines terminating at the San Andreas Fault at right angles, supporting the designation of the fault as a no-flow boundary. No recent water level data across the fault are available in this region; however, DWR reported water level differences of about 50 ft in 1961.

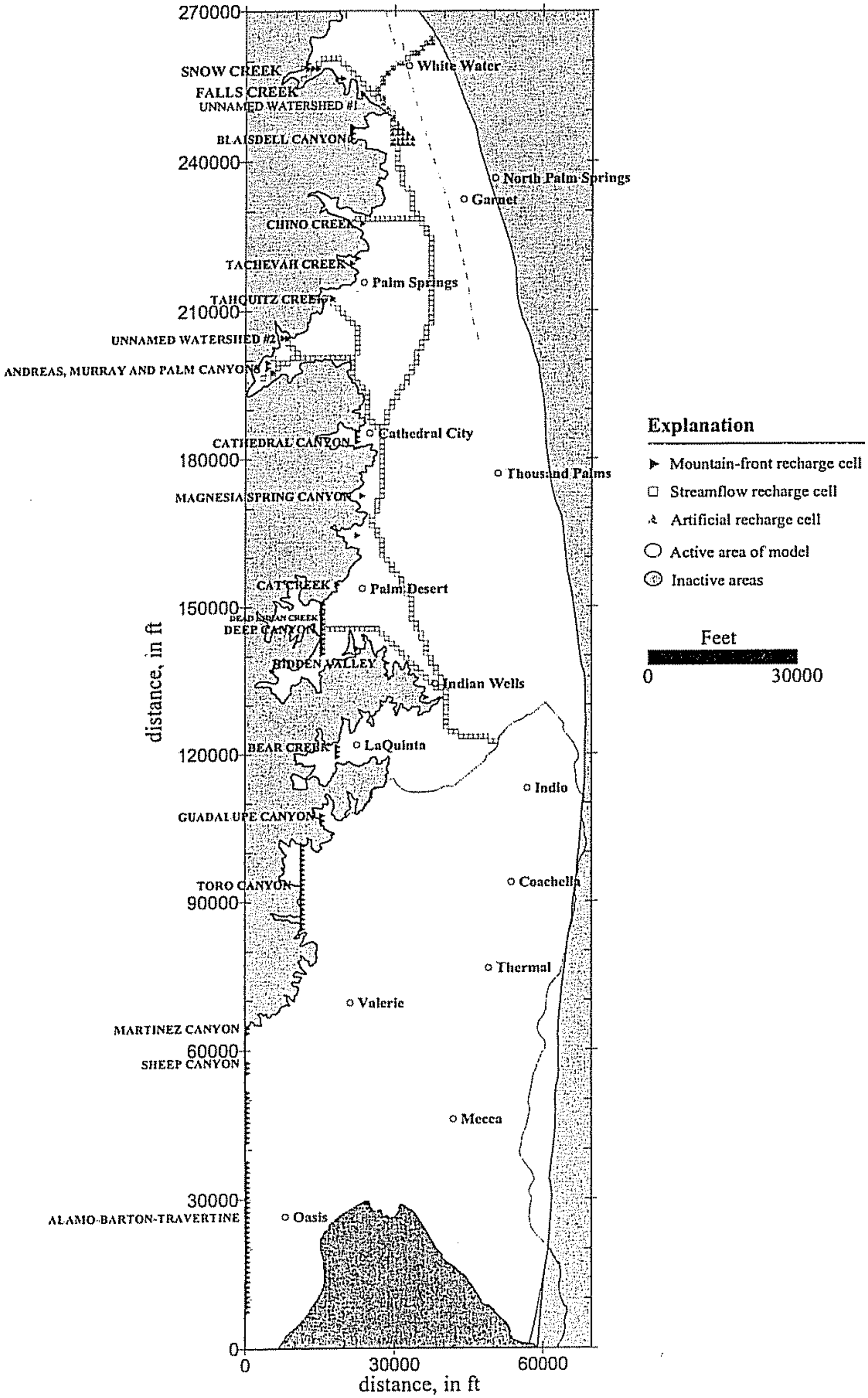
3.2.1.3 Infiltration of Mountain Runoff

Streamflow infiltration and subsurface inflow from mountain watersheds (or mountain-front recharge) from precipitation in the San Bernardino, San Jacinto and Santa Rosa Mountains are the primary natural sources of water to the aquifer system in Coachella Valley. Additional recharge may be derived from precipitation in the Little San Bernardino Mountains. The total volume of tributary inflow varies dramatically from season to season and year to year, due to wide variations in precipitation; perennial streamflow from the mountain watersheds is practically non-existent.

The average annual tributary inflow to the study area during the 61-year model calibration period was estimated for each of the mountain watersheds. Recharge from mountain runoff was estimated by an approach similar to that used by DWR (1964), which involves correlating annual watershed precipitation and runoff. In wet periods, considerably larger amounts of runoff are produced per unit of precipitation than in dry periods. Evapotranspiration and other losses consume a larger fraction of precipitation in dry years than in wet years. In addition, in dry periods, substantial precipitation is required to overcome soil moisture deficits before runoff occurs. Where available, gauged streamflow was used. The method used to estimate runoff from ungauged watersheds involved defining watershed boundaries and determining tributary areas, estimating the average precipitation for the base period 1931-61 for each watershed (DWR, 1964), estimating the annual precipitation (1936-96) for each watershed using precipitation indices, and estimating the annual runoff for each watershed using rainfall-runoff curves. Except for the Whitewater River watershed, 90 percent of the estimated runoff was attributed to streamflow infiltration, and 10 percent of the estimated runoff was attributed to mountain-front recharge. The Whitewater River canyon is suspected to have a greater subsurface flow into the model area than the other mountain tributary watersheds, hence a greater percentage of the estimated runoff was attributed to mountain-front recharge for this watershed.

Subsurface inflow from mountain watersheds was distributed to perimeter cells of the model located in canyons and along mountain fronts as shown on Figure 21. Recharge from infiltration of streamflow was distributed to model cells differently depending on if the year was relatively wet (greater than 1,000 acre-ft of Whitewater River flow at Indio), or relatively dry. With the exception of the Whitewater River, flow beyond mountain-front areas is normally limited to infrequent storm events in wet years. Therefore, recharge from infiltration of streamflow during dry years on major tributaries, and for all years on minor tributaries, was distributed to the perimeter model cells shown on Figure 21. During wet years, there is normally significant tributary flow beyond the mountain-front areas and eventually to the Whitewater River. In these years, recharge from streamflow on major tributaries was distributed to the streamflow recharge cells (Fig. 21) according to a basic river routing model.

Figure 21.
Distribution of mountain-front, tributary and artificial recharge in model.



3.2.1.4 Precipitation on the Valley Floor

Precipitation on the valley floor is not a major source of groundwater recharge due to the low annual rainfall. According to DWR (1964), the average annual precipitation on the valley floor for the 30-year period 1930-60 is about 4.5 inches. This amount of precipitation is normally consumed by direct evaporation or by evapotranspiration from native desert vegetation. During extremely wet periods, precipitation in excess of evapotranspiration and soil moisture deficits may result in both runoff and groundwater recharge; however, this occurs infrequently, and the anticipated recharge rates are small. Thus, such recharge is neglected in the model. These assumptions are consistent with the results of deep percolation studies reported by DWR (1930; 1964).

Within the San Gorgonio Pass area, the greater annual precipitation probably results in some limited groundwater recharge. Estimated annual groundwater recharge in this area is approximately 4,000 acre-ft/year (DWR, 1964).

3.2.2 Artificial Recharge

Since 1973, CVWD and DWA have received SWP water through an exchange agreement with Metropolitan. Water released from Metropolitan's Colorado River Aqueduct flows down the Whitewater River channel to the recharge ponds near Windy Point. A portion of the water infiltrates along the channel, and some evaporates from the ponds before percolating to the water table. Estimates of the amount lost to infiltration in the channel and that to evaporation from the ponds were made for the model. Figure 15 charts the annual amounts of water released from the Colorado River Aqueduct to the Whitewater River. Recharge rates were computed for the infiltration along the channel and at the recharge ponds, and applied in the model as time-dependent specified flux boundaries. Note that in the three years 1985-87, over 650,000 acre-ft of water was released to the Whitewater River. From 1980-87, groundwater levels in the artificial recharge area increased over 350 ft.

3.2.3 Pumpage

Pumpage by wells is by far the largest component of discharge from the groundwater system. Other components of discharge include native vegetation evapotranspiration, flow to drains, and subsurface outflow to the Salton Sea.

Historical pumpage in the upper valley was obtained primarily from previous USGS modeling efforts up to 1967, and from CVWD well discharge meter data for 1984-96. Annual pumpage data not available throughout the historic period were estimated in this study. Principal components of groundwater production in the upper valley include municipal and domestic use, and golf course irrigation.

Historical pumpage in the lower valley is comprised mostly of unmetered agricultural pumpage; accordingly, substantial effort was devoted to estimating the historical agricultural pumpage in this study. Estimates of the volume of surface water delivered to, and crop water use in, each section (one square mile) as a function of space and time were developed in this study to enable calculation of the agricultural pumpage by the consumptive use method (e.g., Diamond and Williamson, 1983). Pumpage in each section was estimated for a number of key years in the historical period from 1936-96. Key years are those that coincided with changing trends in groundwater levels in the lower valley (e.g., 1958, 1968, 1975, 1980, 1987, 1992), and the simulation starting and ending years 1936 and 1996, where sufficient land use data, i.e., crop reports and canal water deliveries, were also available. Pumpage at in-between years was interpolated from the key year estimates.

Agricultural groundwater pumpage in each section was estimated in key years by the following equation:

$$GW = \frac{CU - EP}{IR} - SW$$

where

GW = groundwater pumpage,
CU = consumptive use,
EP = effective precipitation,
IR = irrigation efficiency, and
SW = surface water delivered.

Consumptive use was estimated for each section from crop evapotranspiration (ET) and leaching requirement (LR) data and detailed crop acreage by section records developed in this study. Consumptive use was calculated for each section by multiplying the total acreage of each crop within that section by the sum of its ET and LR and then summing these results for all the crops in that section:

$$CU_{section} = \sum_i CropAcreage_i \times (ET_i + LR_i)$$

where the index i refers to a specific crop type.

Effective precipitation is precipitation that meets the demands of consumptive use, the fraction of annual precipitation that is available for use by crops during the growing season. Effective precipitation was assumed to be negligible. Irrigation efficiency is the percentage of water delivered to the farm that is available for consumptive use.

Total monthly-metered flows for the key years and a map and index sheet identifying the locations of the surface water meters by township, range, and section are maintained by CVWD for lands receiving water from the Coachella Canal. These data were organized into a database and annual totals were calculated for each meter; total metered flows into each section were then computed.

Estimates of golf course demand and some metered municipal and fish farm pumpage data were also factored into the lower valley pumpage database. Additionally, historical unmetered domestic, fish farm and duck club use was estimated.

3.2.4 Return Flows

Return flows are that part of the applied water that percolates back into the groundwater system. Some types of return flows, such as irrigation return and golf course return, can have more than one source of water. For example, Colorado River water from the Coachella Canal is used along with groundwater pumped from wells to supply the needs of agriculture. Thus, agricultural return flows are computed from the total applied water less the water consumed by crop evapotranspiration. Golf course return flows are estimated in a similar manner. Return flows from municipal pumpage were estimated to be a percentage of pumping rates based on assumptions made in the USGS modeling studies, and an analysis of return flows in the upper valley from this study. Other return flows in the model include irrigation returns from diversions of streamflow, and returns from recycled wastewater. Return flows were assigned as infiltration rates to the uppermost model layer.

3.2.5 Evapotranspiration

Groundwater losses to evapotranspiration (ET) by phreatophytes on undeveloped lands are accounted for with an ET boundary condition in the model. Native vegetation on undeveloped lands receives its water supply from direct precipitation and soil water. High evaporation rates and deficient soil water are conditions common to much of the undeveloped land of the Coachella Valley that is underlain by a deep water table. Plants on these lands will transpire little water. However, on undeveloped lands underlain by a shallow water table, phreatophytes receive much of their water from groundwater within reach of their roots and the quantities of water transpired can be substantial.

The ET component of the model is limited to the undeveloped lands within the semiperched zone for the following reasons: (1) significant ET losses are likely to occur only in areas where the water table is shallow, and (2) historically, the only significant areas of undeveloped land within the model domain that are also underlain by a shallow water table lie within the semiperched zone. Development in the semiperched zone is primarily agricultural and total developed area has increased significantly since the early part of the century. Since the 1950's, these developed lands have been generally underlain by agricultural drains at a depth of approximately 10 ft. As the installation of farm drains proceeded, the ET boundary was replaced with a drain boundary condition as described in the next section.

3.2.6 Drain Flows

Effects of agricultural drains in the lower valley were simulated as a function of space and time by building a database of drain locations, depths, and dates of construction from CVWD records. These data were input to the model to specify the drain boundary conditions, which allow computation of flow to drains. Computed and measured drain flows serve as an important benchmark for evaluating accuracy of the model simulations.

The basis for the design of the agricultural drains is described in the CVWD *Drainage Report* (CVWD, 1954). That report and CVWD drain construction records are the primary data sources for establishing the drain boundary conditions. The current drainage system consists of CVWD and on-farm drains. On-farm drains are those constructed by the farmers, at approximately

6-ft depths, and are connected to the CVWD drains. CVWD drains are typically installed at depths of 8 to 10 ft to ensure proper drainage of farm parcels. CVWD operates about 21 miles of open drains (primarily in the Oasis area) and about 166 miles of pipe drains. These drains flow either into the CVSC or directly into the Salton Sea.

The first farm drainage systems were installed in February 1950. With the increased agricultural development made available by Coachella Canal water, installation of both on-farm and CVWD drains progressed rapidly. CVWD records document the location (township, range, section and subdivision), the acreage served, and the date of installation of the drains. Figure 13 shows the cumulative acreage of parcels with drains installed. Currently, drains serve over 50,000 acres of farmland.

Drain boundary conditions were defined by identifying the year when drains were installed, and by mapping drain locations to each model cell. Development of the drain boundary conditions is depicted on Figure 22. Initially, the undeveloped land within the semiperched zone is described with an ET boundary condition; following the installation of farm drains, the ET boundary is replaced by a drain boundary.

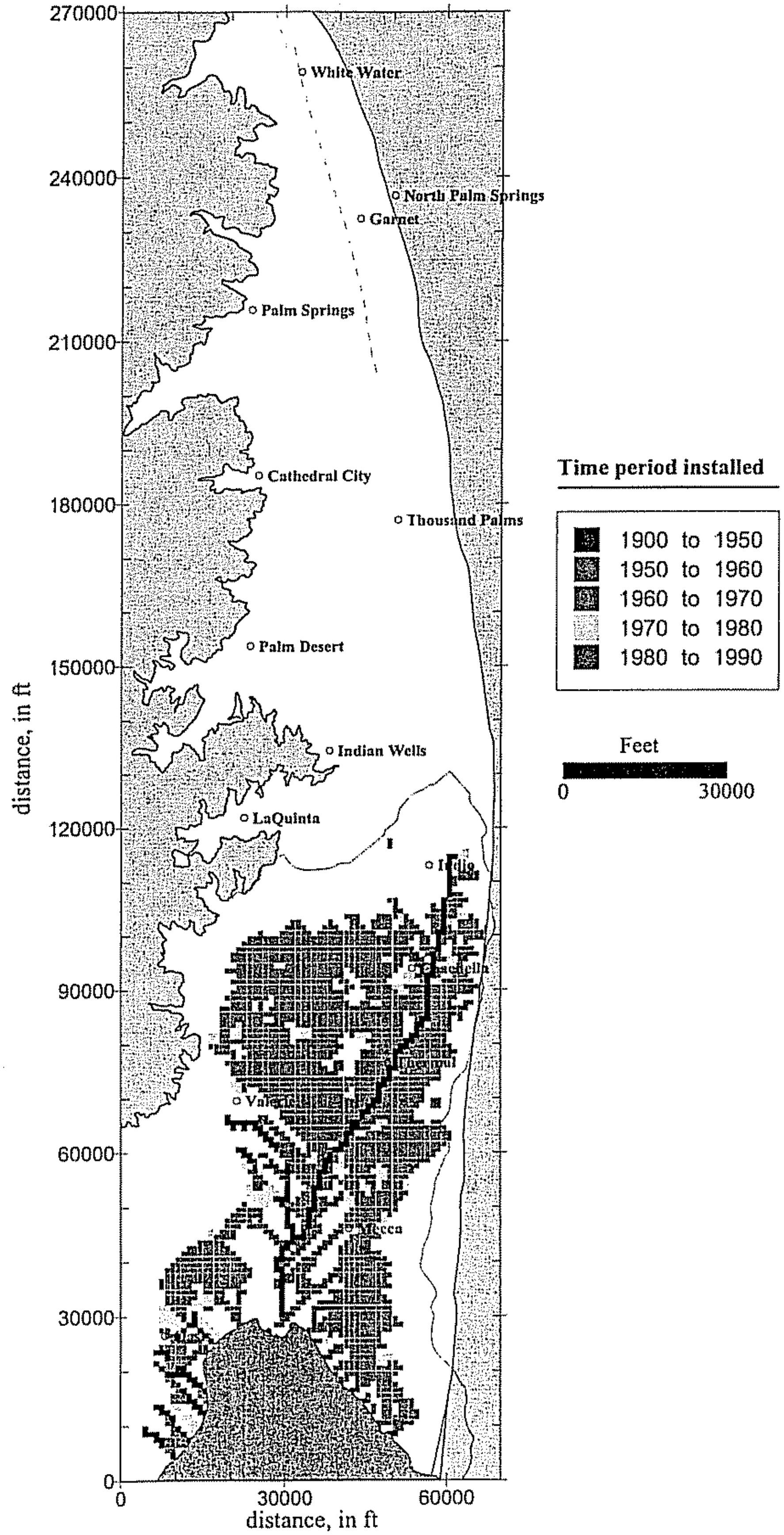
CVWD monitors the flow in each of the drains discharging directly into the Salton Sea and in the CVSC. Data are also collected on direct discharges into the CVSC from sources other than drains. These other discharges include treated wastewater from municipal wastewater reclamation plants, discharges from fish farms, and regulatory releases from the Coachella Canal. The total agricultural drainage is determined from these measured data for comparison with that computed by the model.

3.2.7 Salton Sea

The Salton Sea forms the southeastern boundary of the groundwater basin and the model. Current elevation of the Salton Sea is approximately -228 ft below mean sea level and its average depth is about 30 ft. Evaporation, and the lack of outflow, from the Salton Sea and ancestral seas before it has concentrated salts in water and in alluvial deposits underlying the Sea. Currently, the salinity of the Salton Sea is approximately 43,000 mg/L.

Transient head boundaries were assigned to model layer 1 cells within the Sea (Fig. 18). This type of boundary condition allows recharge from, and discharge to, the Sea. Heads on the Salton Sea boundary are specified as equivalent freshwater heads to account for the density of the seawater. The southeast edge of the model extends more than 5 miles into the Sea and is a no-flow boundary. This configuration allows groundwater to flow underneath the sea and discharge upward. Furthermore, this allows the model to simulate groundwater flow from beneath the Sea into the fresh groundwater basin.

Figure 22.
Development of drain boundary conditions.



3.3 Initial Conditions

Simulation of groundwater flow in Coachella Valley begins in 1936 when sufficient water level data and data needed to estimate pumpage throughout the valley were available. The year 1936 was also the starting time for the USGS model simulations in the upper valley (Tyley, 1974). Additionally, the first extensive study of water levels and pumpage in the lower valley provided these data for 1936 (Pillsbury, 1941).

A groundwater elevation contour map of the entire valley was created for 1936 and heads from this map were input as initial conditions to the model (Fig. 23). These heads are based on water level measurements in wells tapping the unconfined and lower aquifers, and were assigned to model layers 2, 3 and 4, as well as the unconfined areas of layer 1. Initial water levels within the semiperched zone of layer 1 were estimated from these data and adjusted where necessary to not exceed land surface elevation.

3.4 Parameters

Aquifer parameters include thickness, hydraulic conductivity and storage coefficient. These parameters affect the rate of groundwater movement and the volume of water taken into and released from storage. General descriptions of the data and methods used to estimate the initial parameter values in the model are given in this section. Refinements to initial parameter values were made during model calibration.

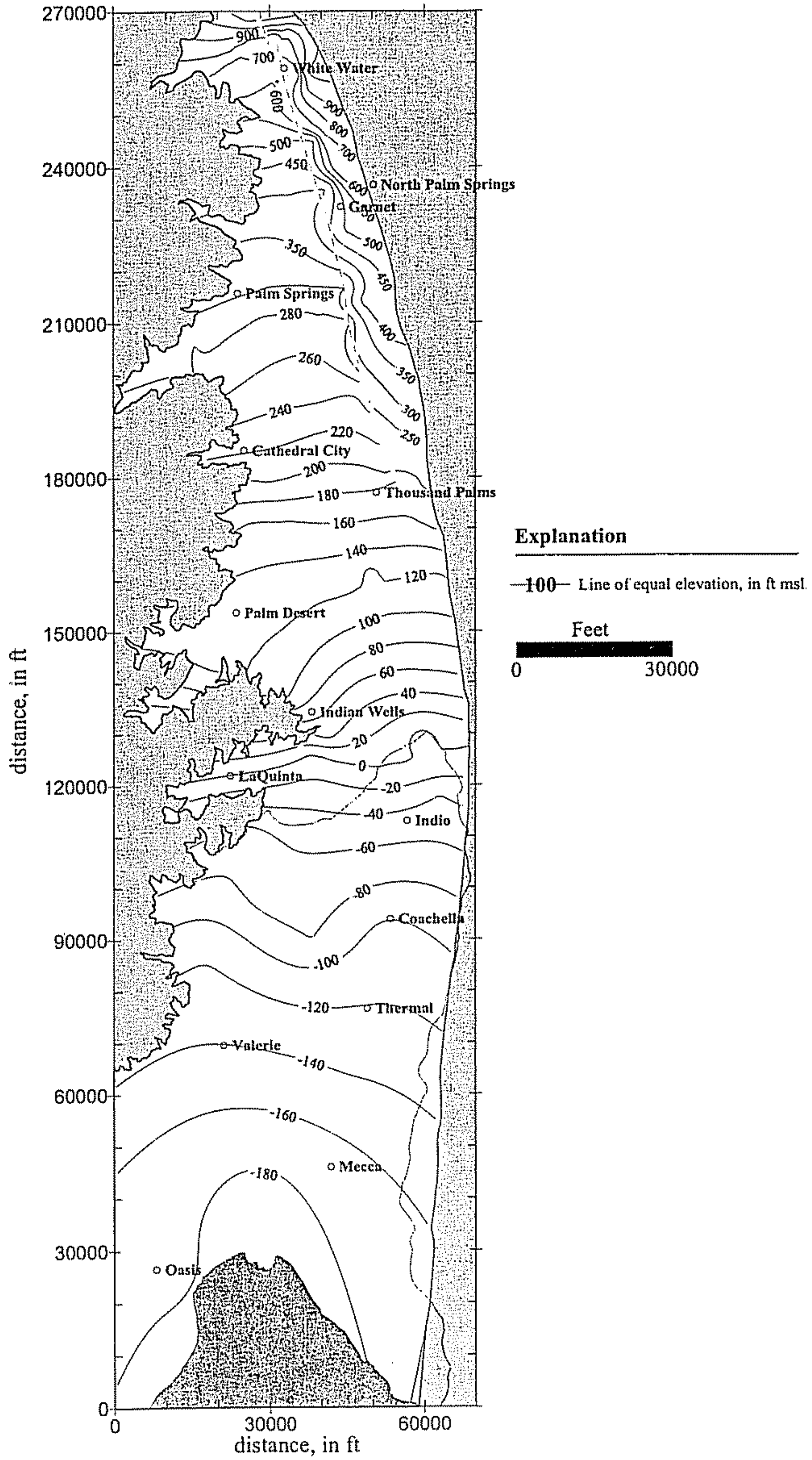
3.4.1 Aquifer Thickness

Elevation of the tops and bottoms of model layers are referenced to land surface elevations, and hence the topography, obtained primarily from USGS digital elevation models (DEM) and topographic maps of the Coachella Valley area. Total aquifer and hydrostratigraphic unit thickness then follows from elevations assigned to the mesh layers.

In the lower valley, layer thickness follows geologic characterizations by DWR (1964; 1979) that were corroborated by analysis of subsurface data in this study; the layers were designed to closely approximate the main aquifer units in the lower valley. For example, layer 1 approximately corresponds with the semiperched zone (100 ft thick), layer 2 with an upper aquifer unit (80 to more than 240 ft thick), layer 3 with an aquitard (80 to more than 240 ft thick), and layer 4 with a lower aquifer unit (1,000 ft thick). In the upper valley, aquifer thickness estimated by USGS (Reichard and Meadows, 1992), was initially used and later revised during model calibration.

The model tracks the location of the water table relative to the layer elevations. If the water table drops below the bottom of a layer at a location, the corresponding cell in that layer is made inactive. If the water table later rises above the layer bottom, the cell is reactivated. Outside the semiperched zone, thickness of layers 1, 2, and 3 were adjusted to minimize this conversion to dry cells.

Figure 23.
Contours of measured groundwater elevations in 1936.



3.4.2 Hydraulic Conductivity

Initial estimates of aquifer transmissivity (T) were obtained in part from previously calibrated values used in Reichard and Meadows (1992) for the upper valley, some pumping test results for the lower valley, and fairly abundant specific capacity data for the entire valley. Hydraulic conductivity (K) of the confining bed in multiple aquifer zones was estimated based on the sediment texture and heterogeneity and was treated as a calibration parameter. Similarly, vertical K (K_v) of the aquifer zones was based on the degree of fine-grained bedding present in electric and drillers logs as well as past experience with three-dimensional heterogeneity in sedimentary basins; this parameter was also adjusted in calibration.

Time, drawdown and discharge data from 50 short-term pumping tests (generally of 3-hour duration) on CVWD wells were analyzed for transmissivity using the graphical method of Cooper and Jacob (1946). Due to incomplete well development or other unknown test conditions, half of the tests were rejected for analysis. Transmissivity estimates determined from the analyses were plotted against specific capacity (S_c) and regression was used to develop an equation describing the relationship between T and S_c. This equation was then applied to other wells throughout the valley having S_c test data in the database. Transmissivity can be expressed as the product of hydraulic conductivity and aquifer thickness, or $T = K \times b$, where b is the aquifer thickness. Thus, initial values of K were determined from the T estimates.

3.4.3 Specific Yield and Specific Storage

Distribution of specific yield (S_y) from Reichard and Meadows (1992) was initially used in the upper valley for model layer 1; these values were subsequently modified slightly during calibration. Similar specific yield values were initially estimated for the unconfined areas and semiperched zone in the lower valley; these values were later adjusted during calibration.

Specific storage (S_s) values were estimated for each of the model layers 2, 3 and 4, and were multiplied by layer thickness to obtain storage coefficient (S) for each model layer. S_s varied in confined vs. unconfined areas.

3.5 Garnet Hill Fault

The Garnet Hill Fault (Fig. 3) is located about 1.5 miles south of, and is oriented generally parallel to the Banning Fault. DWR (1964) suggested that the fault has not displaced Recent alluvium, but is effective as a barrier to groundwater flow below depths of 100 ft, based on water-level measurements at the fault. The area between the Garnet Hill Fault and the Banning Fault is named the Garnet Hill Subarea (DWR, 1964). The few wells present in the Garnet Hill Subarea indicate that water levels are higher in the subarea than in the adjacent Palm Springs Subarea opposite the Garnet Hill Fault.

The Garnet Hill Fault is simulated using the Horizontal Flow Barrier Package (Hsieh and Freckleton, 1993). Model-calibrated transmissivities along the Garnet Hill Fault from Swain (1978) were used to compute initial estimates of hydraulic conductivity of the fault barrier. These estimates were modified slightly during calibration.

3.6 *Land Subsidence*

Groundwater levels throughout most of Coachella Valley are nearing or have already fallen below historic lows, causing concern about potential land subsidence. Thus, CVWD entered into a cooperative agreement with USGS in 1996 to establish a network of geodetic monuments for monitoring potential subsidence in the lower valley (Ikehara et al., 1997). Capability for modeling of subsidence exists in the present model via implementation of the Interbed-Storage Package (Leake and Prudic, 1991). Because evidence for subsidence in the valley is unclear, however, the parameters in the Interbed-Storage Package have been set so that simulated subsidence remains small (less than approximately 1 ft). It is suspected that substantial drawdown northwest of Point Happy, near the transition between the upper and lower valley, induced some subsidence that was not detected. Continuing overdraft raises the probability of future subsidence, calling attention to the importance of future monitoring of the established network.

4 CALIBRATION AND HISTORICAL SIMULATION RESULTS

Model calibration is the process of refining the model representation of the hydrogeologic framework, estimates of boundary condition heads and fluxes, and aquifer parameters to improve correspondence between measured data and simulated results. Successful calibration demonstrates the ability of the model to simulate historical water levels and fluxes throughout the basin.

The model was calibrated, using standard methods (ASTM D5490, D5981), to measured water levels and drain flows in the period 1936-96. Measured data on groundwater levels, artificial recharge amounts, drain flows, and elevation of the Salton Sea were available in this historical period. The data show significant changes in groundwater levels, both up and down, owing to major historical shifts in both pumpage and recharge. Thus, a major goal has been to simulate these important historical changes, thereby providing a rigorous test of the ability of the model to adequately simulate effects of future fluctuations in pumpage and recharge. The results are generally excellent, despite the complexities inherent to the Coachella Valley groundwater system.

The modeling effort has been devoted more to estimating historical pumpage and recharge, and to hydrologic data analysis, than to fine-tuning of model parameters during calibration. The following paragraphs briefly discuss the main boundary conditions and parameters adjusted during calibration:

- Although some metered pumpage data and previous estimates of pumpage were available for various time periods, historical pumpage and return flows in the current model were largely estimated in this study through a phased approach. In each phase, improvements in the model databases on historical pumpage and recharge produced improvements in the agreement between measured and historical water levels and drain flows. For example, in the upper valley, initial calibration runs lacked adequate pumpage data for the period 1969-83. When these data were developed and included in the model, much closer agreement between measured and observed groundwater levels was achieved.

- Ephemeral streamflow recharge was at first simulated as constant in time, but test runs of the model showed that some of the major trends in water levels could not be reproduced without varying the recharge in accordance with infrequent but significant flood events. The data for time-varying ephemeral streamflow recharge was based on a hydrologic analysis of precipitation and runoff in watersheds sourced in the San Jacinto and Santa Rosa Mountains as well as the Whitewater River watershed.

- The main parameters adjusted in the calibration were K, S_s, S_y, and vertical hydraulic conductivity (K_v). For example, K estimates were refined in regions where well test data were sparse. Magnitudes of all such adjustments were small to moderate and were consistent with available data and conceptual models.

- Measured semiperched zone water levels and CVWD monitored drain flows were important calibration targets for the boundary condition representing evapotranspiration from native vegetation.

Model results include computed water levels for each active node in the model mesh. Computed water levels were plotted for many wells at various depths and locations throughout the valley and were compared with measured water levels in the wells. Locations of some representative wells are shown on Figure 17. Charts of measured and simulated water levels are shown on Figure 24 for several representative wells in the valley. These charts demonstrate that the model accurately simulates the varied historical changes in water levels in wells at widely different locations in the valley.

Two years, 1968 and 1992, were selected from two dissimilar hydrologic periods to present model results for groundwater elevations throughout the valley. Figure 25 shows contours of measured water levels and a post of residual values in the upper aquifer for 1968. A *residual* is the difference between the computed and measured water level at a well location. Figure 26 shows contour plots of measured and simulated groundwater elevations (a) and residuals (b) in the lower aquifer in 1968. Similar plots for 1992 are shown on Figures 27 and 28. These maps show that the model very closely simulates the observed water level patterns throughout the valley. Additionally, most of the residuals are within 20 ft, in very good agreement with the measured data.

Simulated versus measured water levels for wells in the valley with water level data in the years 1968 and 1992 are shown on Figures 29 and 30, respectively. The one-to-one correspondence line is plotted for comparison. The close agreement between the water level data and the line of zero residuals indicates a successful calibration. Further, there is little or no pattern (correlation) between positive and negative residuals (above and below the line), and the magnitude of the residuals is very small (usually less than 2 percent) compared to the total change in head along the valley.

Figure 24.
Measured and simulated groundwater levels in selected wells.

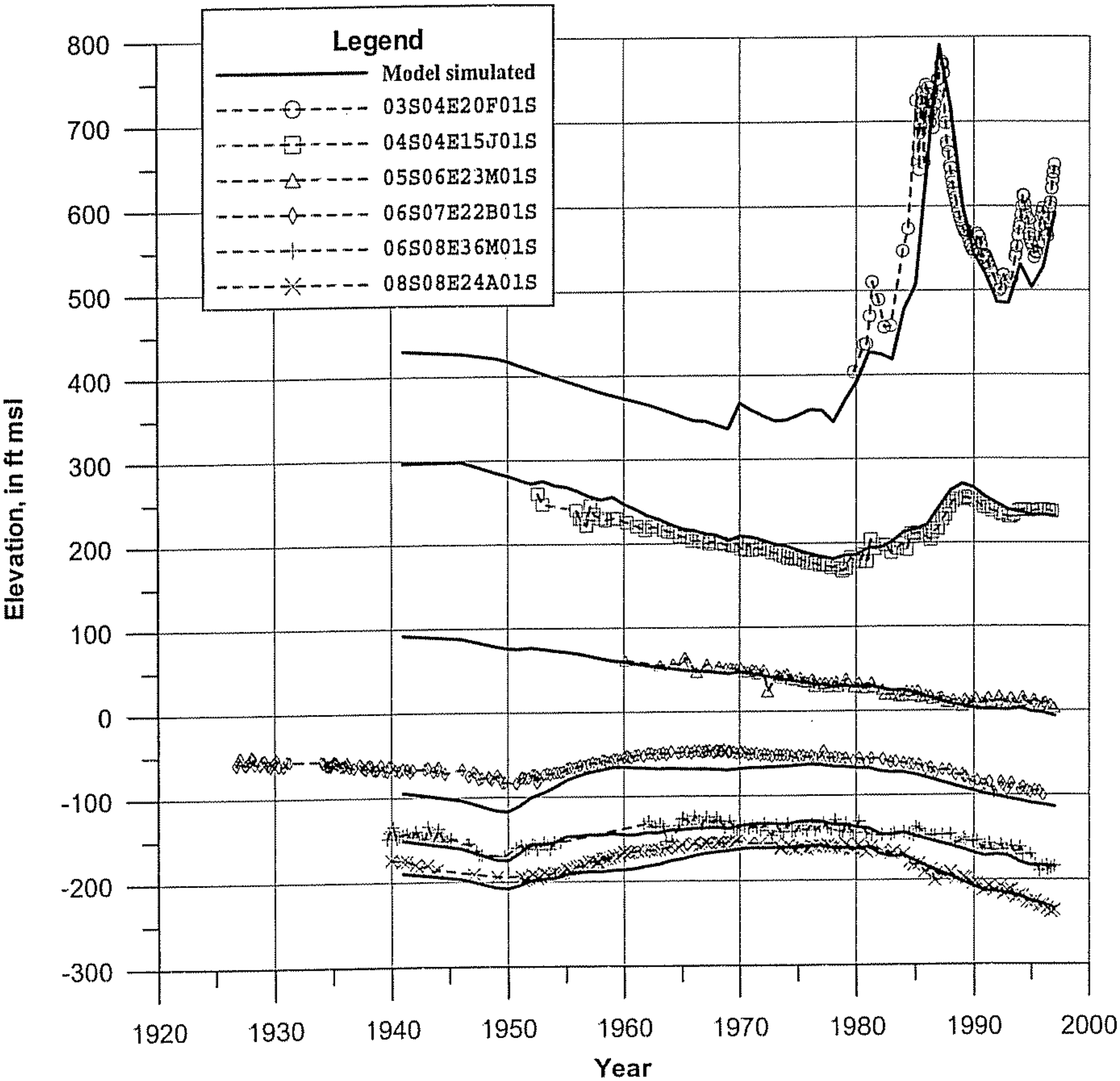


Figure 25.
Measured groundwater levels and residuals in the upper aquifer, 1968.

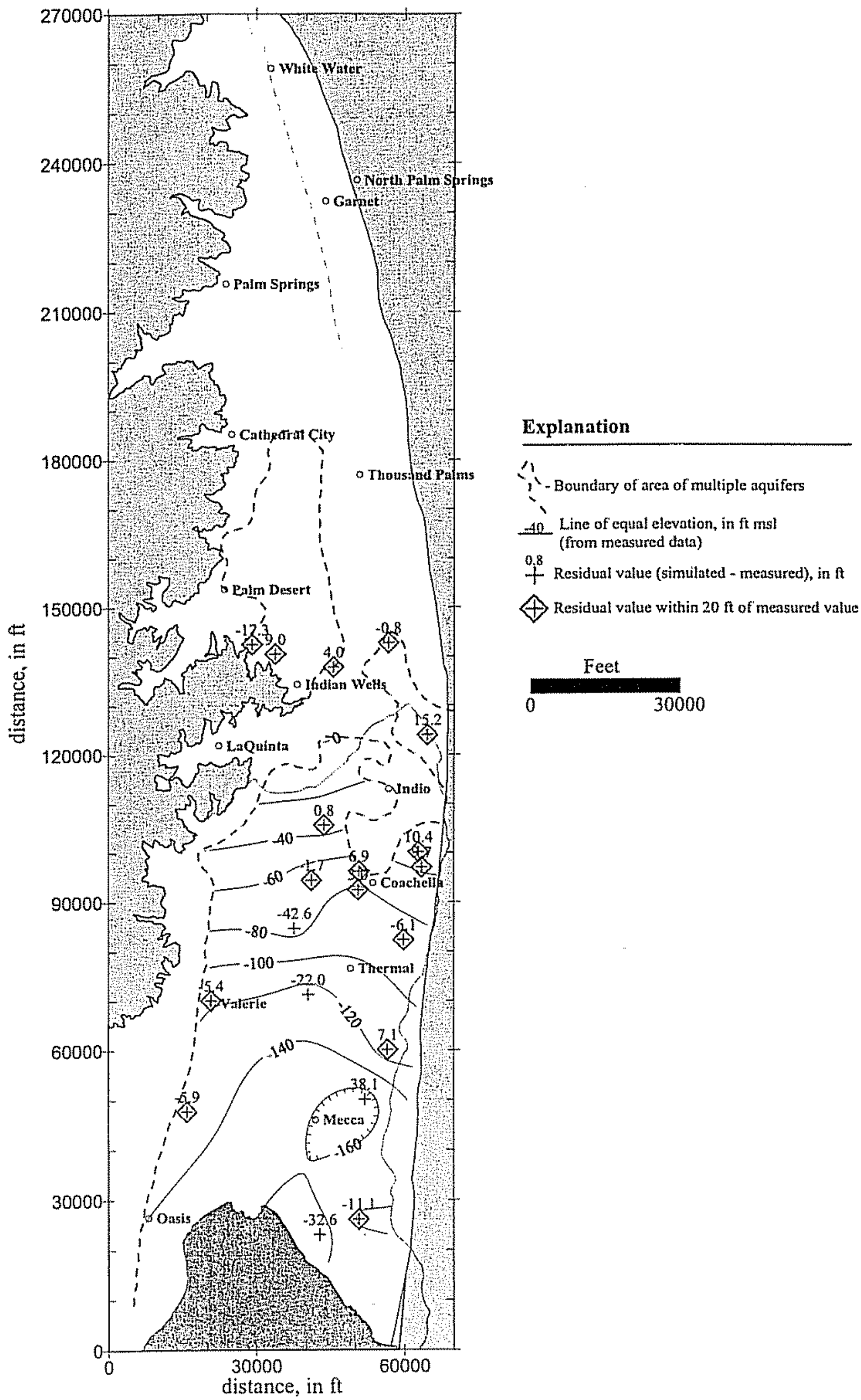


Figure 26.
Measured and simulated groundwater levels and residuals in the lower aquifer, 1968.

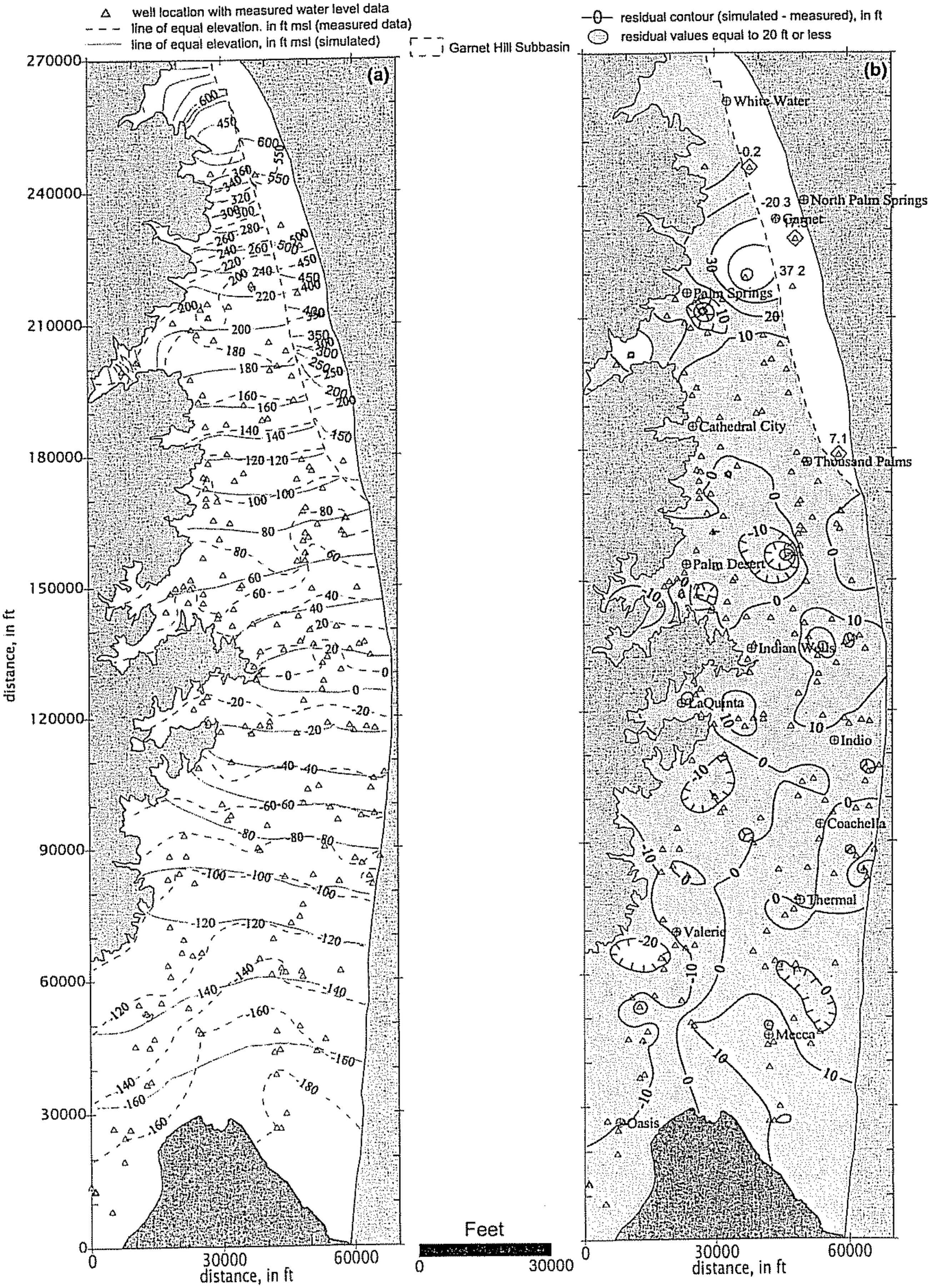


Figure 27.
Measured groundwater levels and residuals in the upper aquifer, 1992.

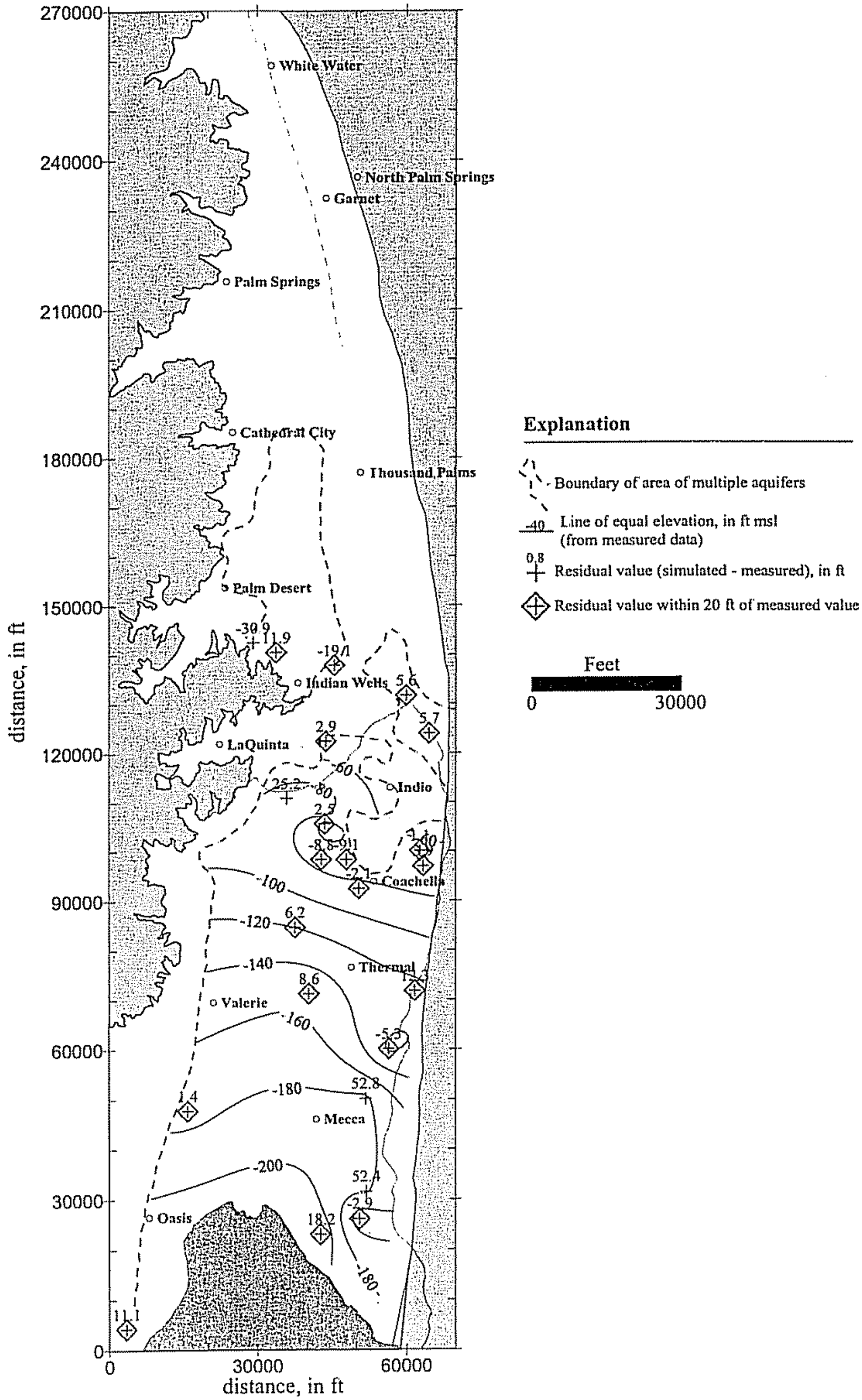


Figure 28.

Measured and simulated groundwater levels and residuals in the lower aquifer, 1992.

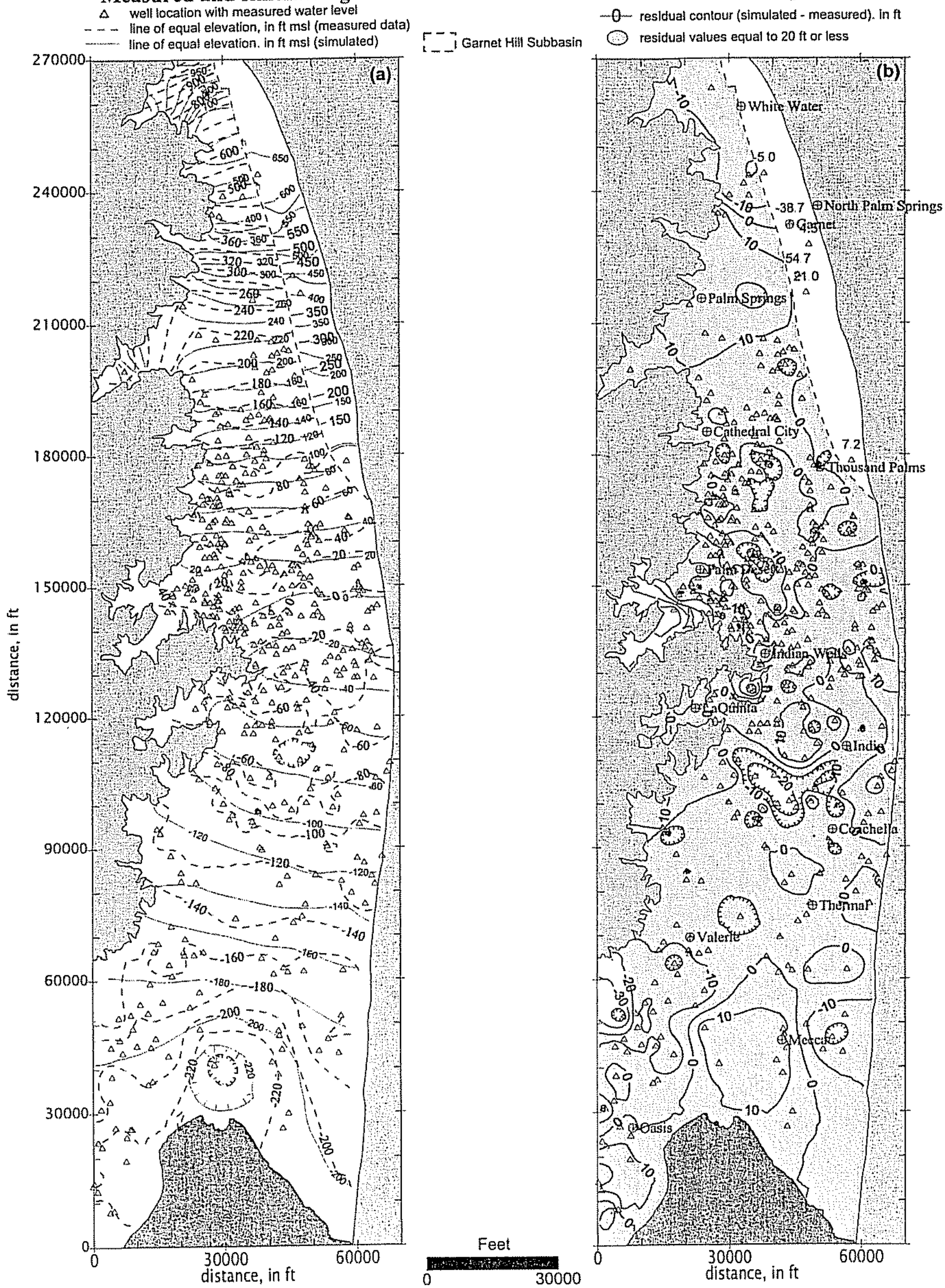
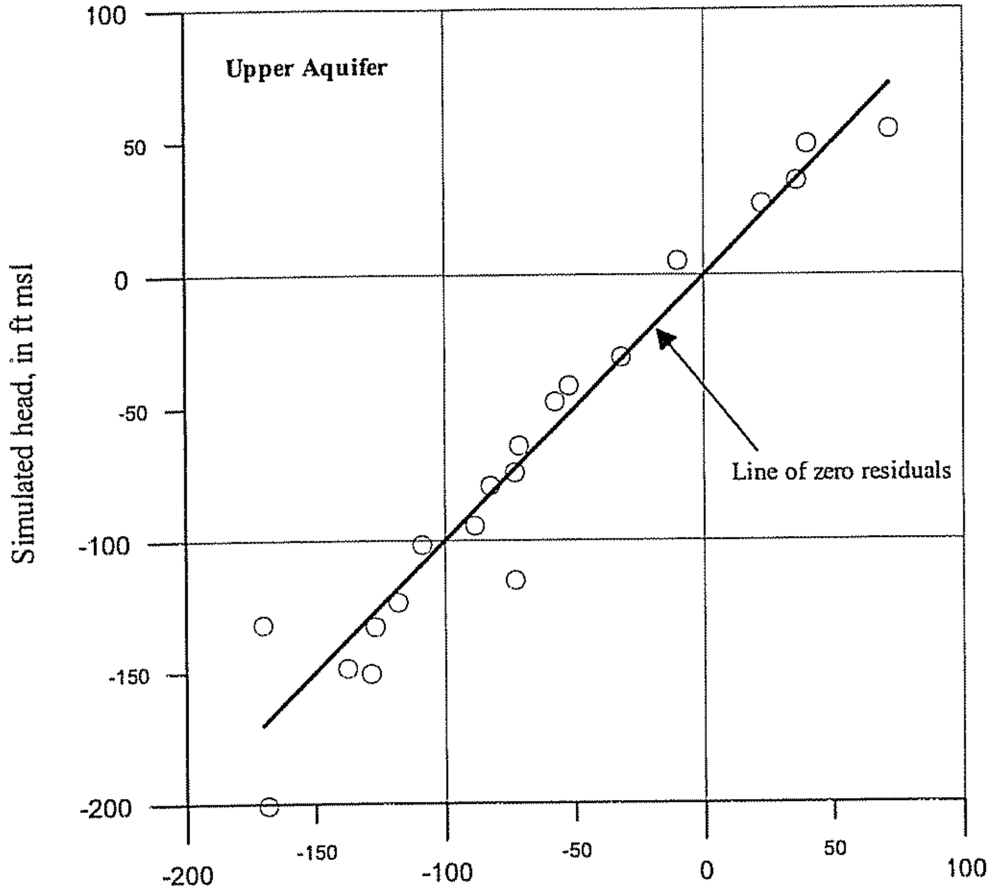


Figure 29.
Measured versus simulated groundwater levels in the upper and lower aquifers, 1968.



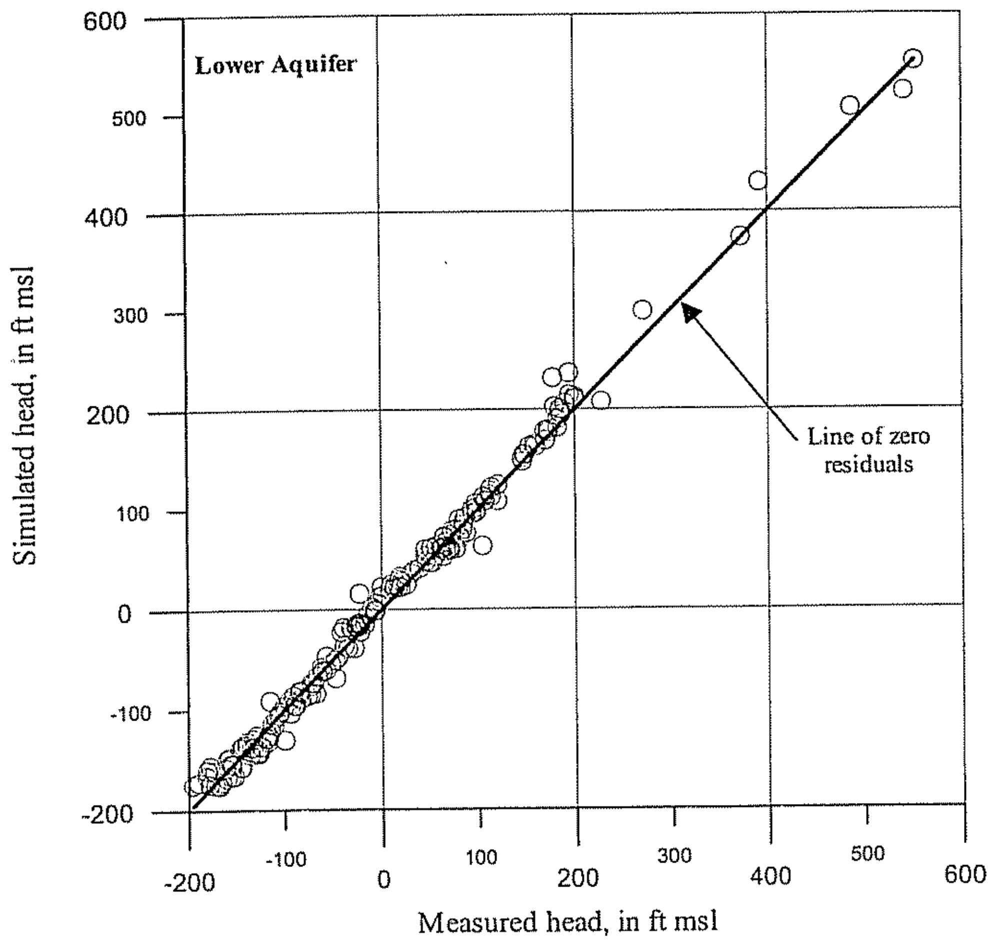


Figure 30.
Measured versus simulated groundwater levels in the upper and lower aquifers, 1992.

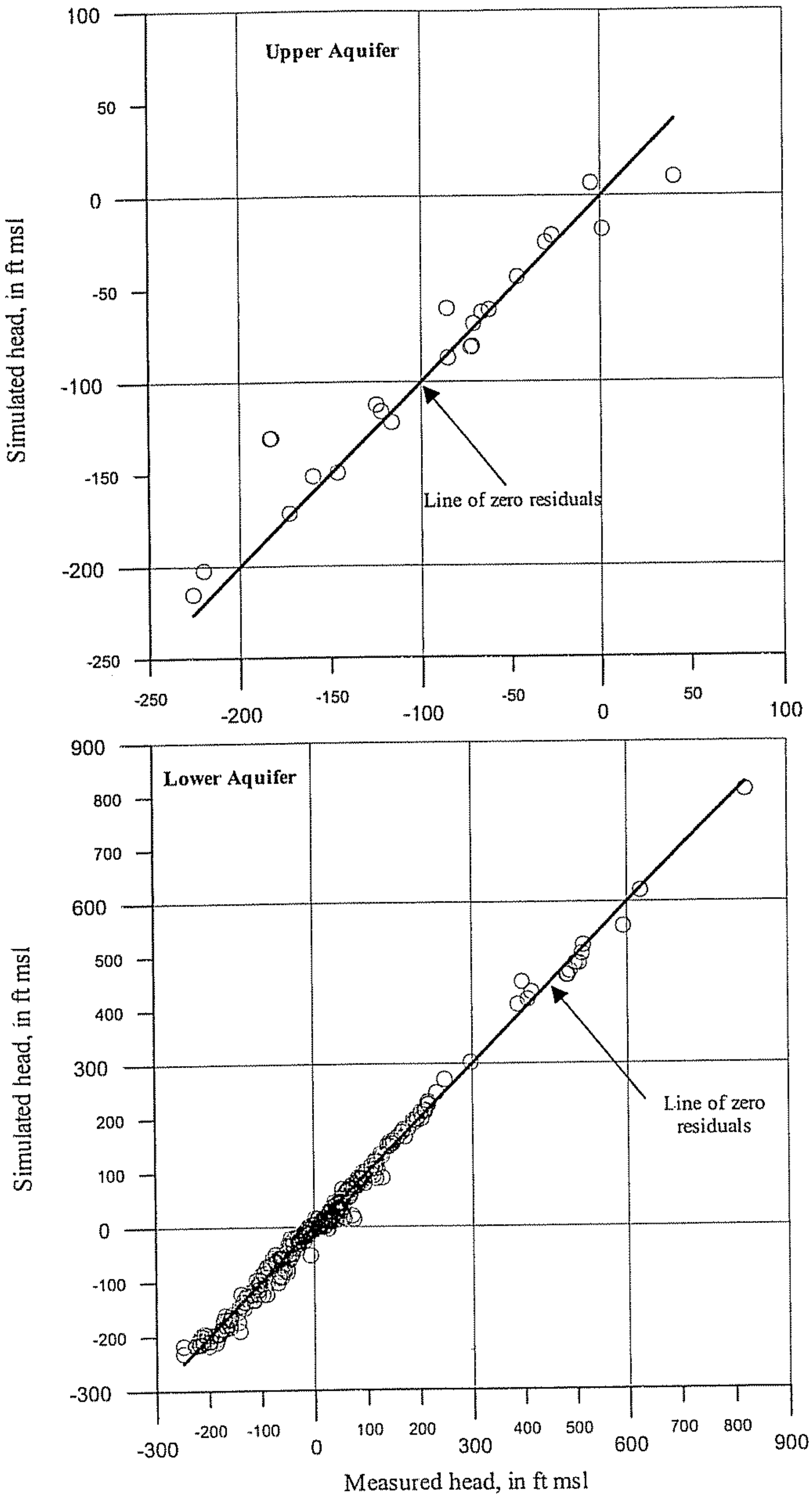


Figure 31 shows a histogram of the model deviations (residuals) from annual average groundwater elevations for all available measured water level data from wells in the period 1936-96. Where measured groundwater level data were available in a well, an annual averaged data value was compared with the model-simulated value at the mid point of the year. This chart is convenient for showing the distribution of model residuals for the entire calibration period. Note that approximately 86 percent of the residuals in the upper aquifer and 85 percent of the residuals in the lower aquifer are within 20 ft. The mean of the residuals for the upper aquifer is 3.86 ft and that for the lower aquifer is 3.39 ft. These are excellent results, considering the long historical period, the great number and varied location of wells, and the large range in measured water levels (over 1,100 ft) along the basin.

Model computed drain flows are compared with measured agricultural drain flows in Figure 32. The very good agreement provides additional, strong evidence that the model is capable of simulating real trends in both water levels and flow rates.

In summary, progressive improvements in the model by inclusion of increasing amounts of data and a refined conceptual model, produced excellent agreement between measured and simulated groundwater levels and drain flows for the period 1936 to 1996. These results indicate the model is valid for simulating the kinds of fluctuations and trends experienced by the system in the past.

5 PEER REVIEW

CVWD commissioned three internationally respected experts in groundwater hydrology and modeling to conduct a peer review of the groundwater model. The committee included Dr. Irwin Remson, Mr. Steven P. Larson, and Dr. James W. Mercer. Given the purpose of the model to aid CVWD in managing groundwater resources in Coachella Valley, the following goals were established for the peer review process:

1. Given the conceptual model, numerical model construction and performance in historical simulation, comment on model reliability.

2. Evaluate suitability of model to simulate prevention of intrusion of groundwater from the Salton Sea and stabilization of groundwater levels in response to management options of artificial recharge.

3. Recommend changes, if needed, to achieve the above.

The peer review process consisted of a review of background materials, site reconnaissance, and participation in a series of meetings with the groundwater modeling team. Three meetings took place over the course of seven months, and consisted of presentations by the modeling team on conceptual and technical aspects of the model. The peer review panel recommended some modifications to the model at the first meeting that were completed and reviewed at the second; additional calibration was recommended at the second meeting that was completed and reviewed at the third. In this way, comments by the panel were considered and the modeling approach was modified as appropriate.

Figure 31.
Histogram of residuals, 1936-96.

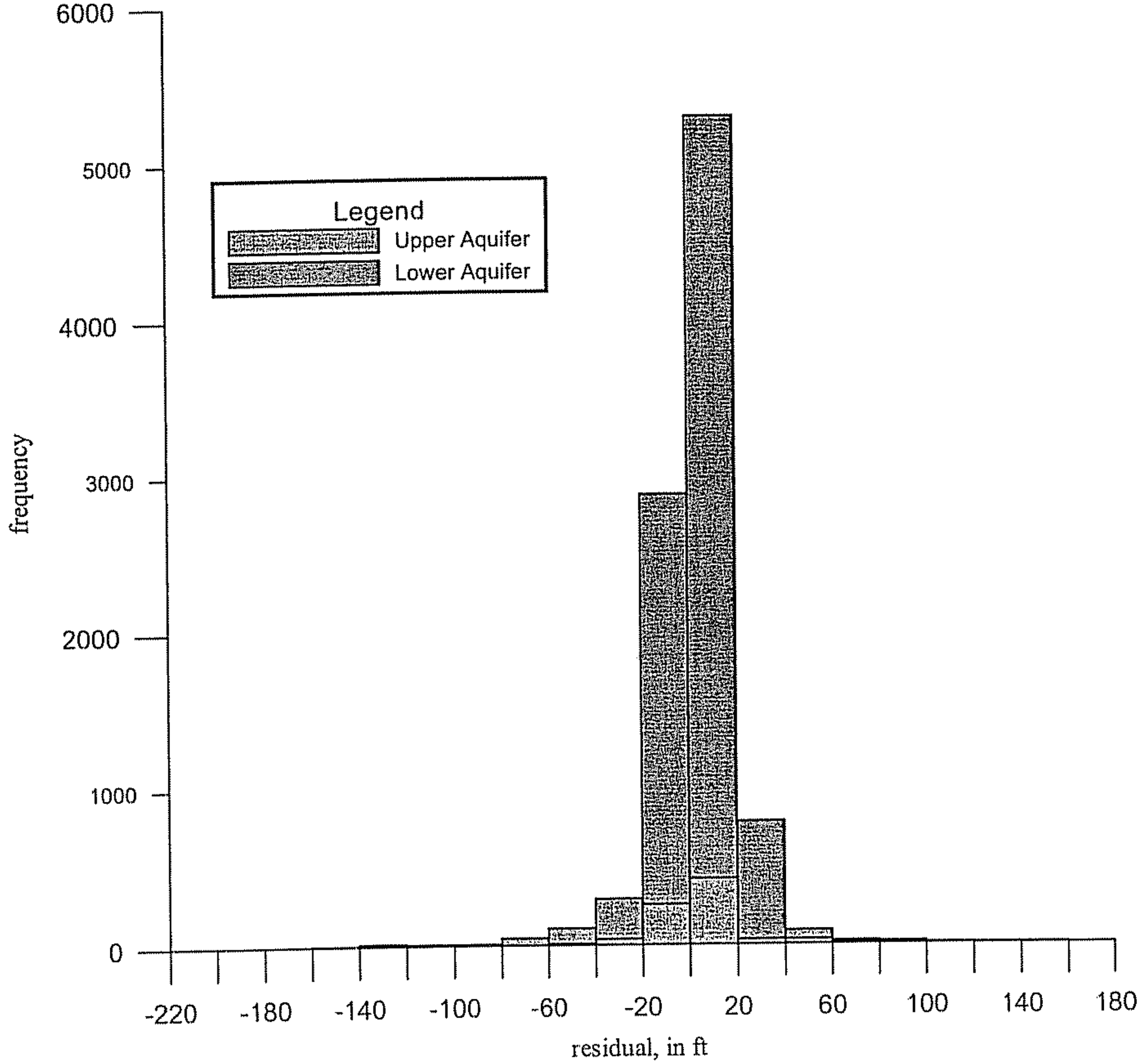
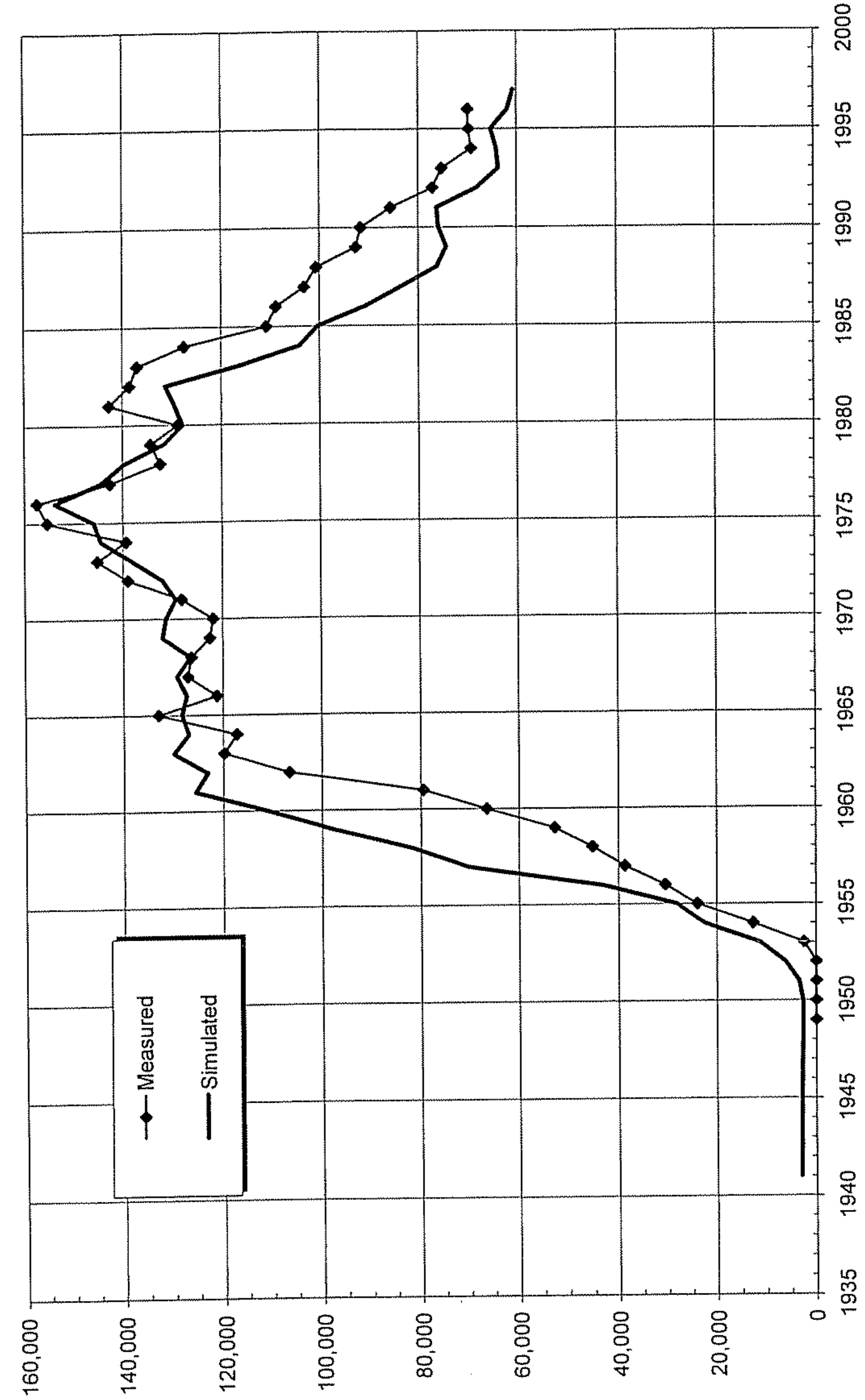


Figure 32.
Measured and simulated agricultural drain flows.



The peer review committee concluded the model calibration is excellent based on the calibration results, the nature of the hydrogeologic system, and the fact that the model is calibrated using databases that are extensive in both space and time (Larson et. al, 1998). The committee concluded "the overall model is valid" and further that "continued study should be restricted to specific local problems." The committee also noted that any changes in local areas would not affect the overall model, and that the model may be used to help evaluate and compare the proposed water management plan alternatives.

6 RESULTS OF PREDICTIVE SIMULATIONS

The model was used to simulate numerous different water management plan alternatives under consideration by CVWD. Water use for each alternative from 1997 to 2035 was estimated, and appropriate model boundary conditions were developed for this period. Results of the predictive simulations were analyzed in terms of (1) sustainability of groundwater levels and (2) maintenance of net groundwater discharge to the Salton Sea.

In developing the model boundary conditions for the planning period 1997-2035, the following assumptions were made:

- Average recharge rates from infiltration of streamflow and mountain runoff over the 61-year history-matching period from 1936-96 are applicable to the simulation period 1997-2035.

- Actual Salton Sea elevation was used in 1997-99 and held constant at 1999 levels for 2000-2035.

- Minimum SWP inflows were assumed to be 50,000 acre-ft per year

- No additional drains were installed after 1996.

Pumpage and recharge estimates were made separately for each alternative as discussed in the Water Management Plan[1]. To demonstrate the model application, two of the alternatives under consideration are briefly discussed in the following sections. Model results are presented including contour plots of simulated groundwater levels in the main aquifer system (layer 4) for the year 2035 and contour plots of the difference between these and simulated groundwater levels at the end of 1999.

6.1 *Alternative 1 – No Project*

The No Project alternative would not involve any additional management actions beyond CVWD's ongoing activities. These include:

- continued groundwater recharge in the upper valley at historical rates (approximately 50,000 acre-ft per year),

[1] Contact CVWD for more information.

- minimal reduction in groundwater use by providing alternative sources of water to golf course and agriculture,

- current levels of domestic, golf course, and agricultural water conservation, and

- information and education programs would be maintained at existing levels.

Figure 33 shows a contour plot of simulated groundwater levels in 1999; vectors indicate the general direction of groundwater flow. Figure 34 shows a contour plot of simulated groundwater levels for 2035. Figure 35 shows a contour plot of the difference in heads between 1999 and 2035; the shaded areas indicate water level declines greater than 200 ft. The continuing overdraft conditions simulated in Alternative 1 raise the concern for potential land subsidence in the area between Palm Desert and Indian Wells. This is due to the existence of significant fine-grained materials at depth in this area (Fig. 6) and because the simulated water-level declines fall well below historical lows.

6.2 Alternative 4 -- Combination Alternative

Alternative 4 is a combination of the most feasible and cost-effective measures evaluated by CVWD. It includes maximizing the use of Coachella Canal water and recycled water, urban and agricultural conservation measures, increasing upper valley groundwater recharge by approximately 40,000 acre-ft per year, and recharging the lower valley groundwater with imported Coachella Canal water by approximately 80,000 acre-ft per year.

Alternative 4 results are identical to those for Alternative 1 in the year 1999. Figure 36 shows a contour plot of simulated groundwater levels in 2035 for Alternative 4. Figure 37 shows a contour plot of the difference in heads between 1999 and 2035; under this alternative, groundwater levels would rise near the proposed artificial recharge areas, and over much of the lower valley.

7 CONCLUSIONS

Excellent agreement, both valley-wide and throughout the 61-year history-matching period, between measured and model simulated water levels and drain flows, demonstrates that the Coachella Valley groundwater model has been calibrated successfully. The excellent match between measured and simulated conditions was based on a sound conceptual model, and was obtained largely through (1) careful, methodical development of progressively more accurate databases on groundwater pumpage and recharge estimates, and (2) hydrogeologically prudent, moderate adjustments in aquifer parameters.

Results indicate that the model is valid for analysis of regional management problems provided the imposed stresses on the system are similar to those during the calibration period. Regarding field applications of the management alternatives, infiltration rates for artificial recharge projects should be verified by pilot tests, and review of local hydrogeologic conditions should accompany any proposed plans. Any improvements in local hydrogeologic information can readily be included in the model, enhancing the predictive capability of the model locally, without affecting the overall results.

Figure 33.
Alternative 1 simulated groundwater levels in layer 4, 1999.

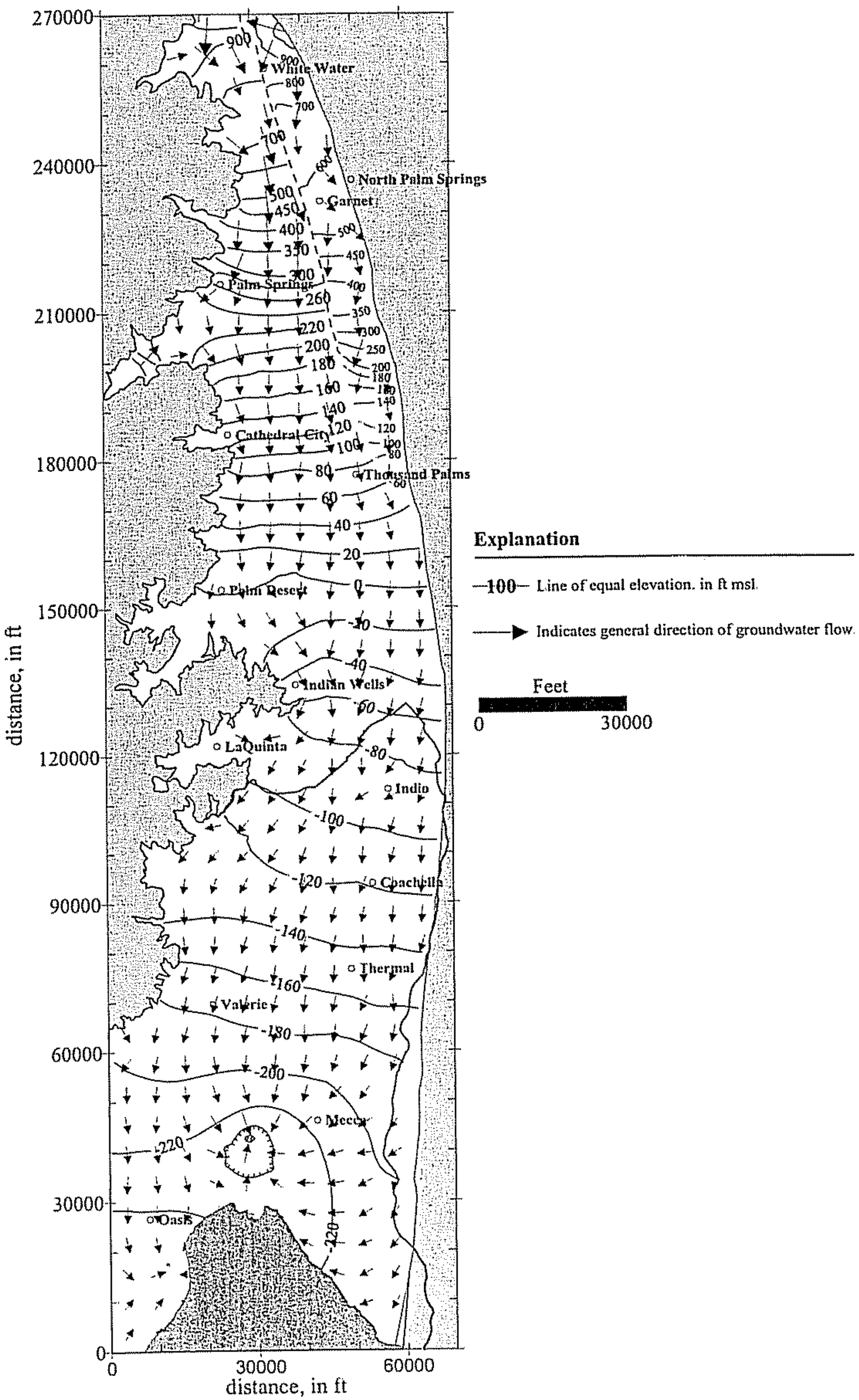


Figure 34.
Alternative 1 simulated groundwater levels in layer 4, 2035.

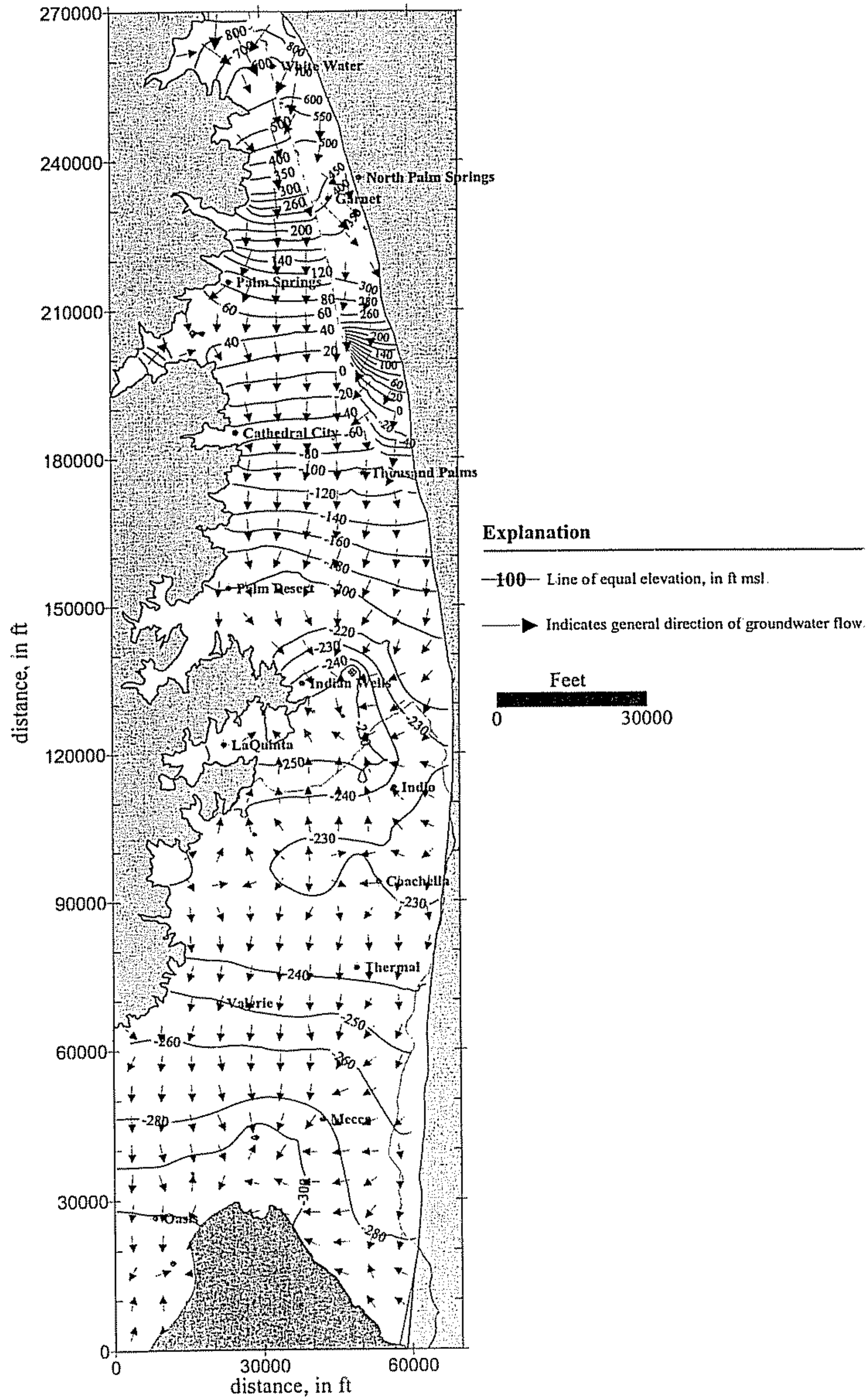


Figure 35.
Alternative 1 potential water-level decline in layer 4, 1999-2035.

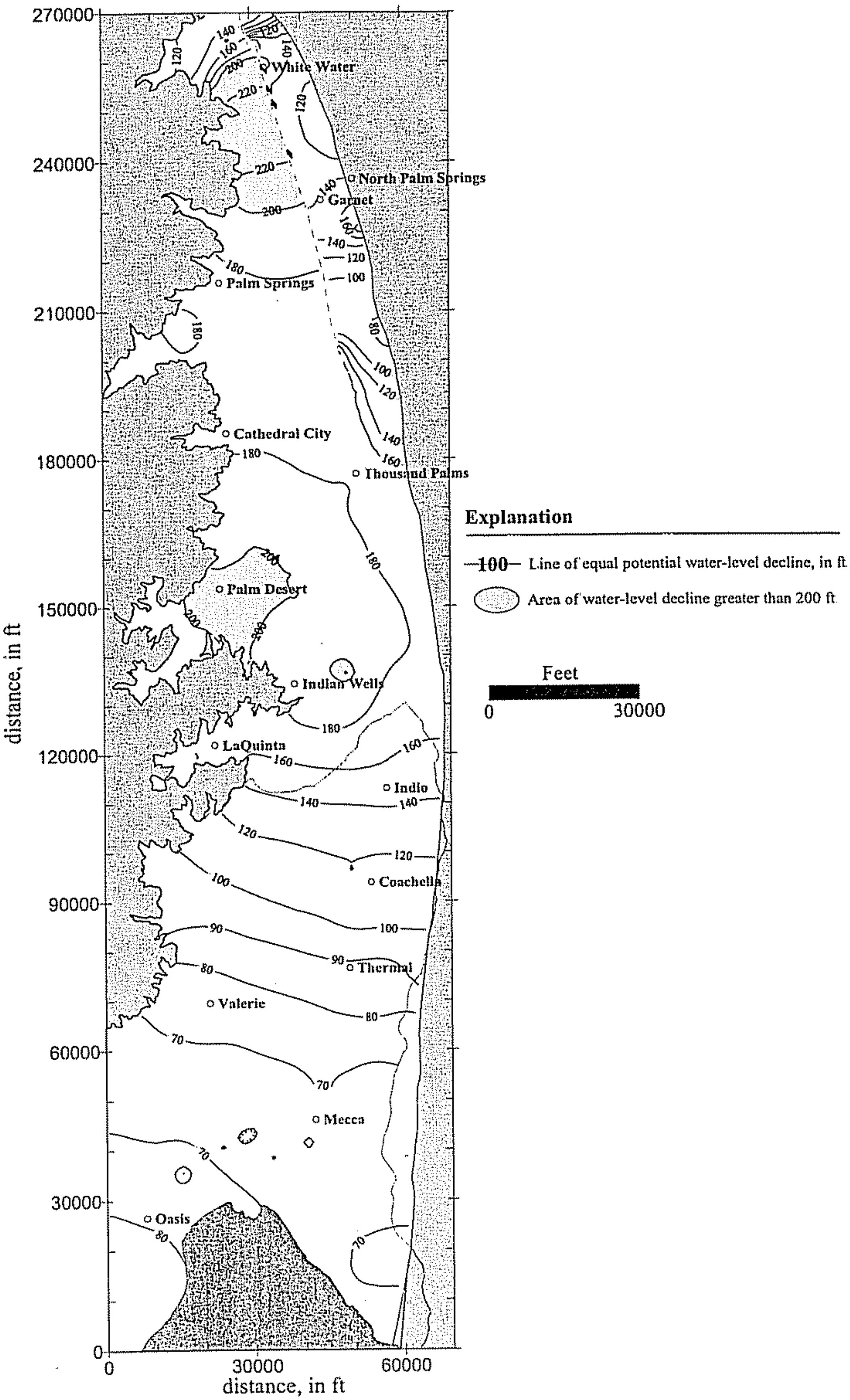


Figure 36.
Alternative 4 simulated groundwater levels in layer 4, 2035.

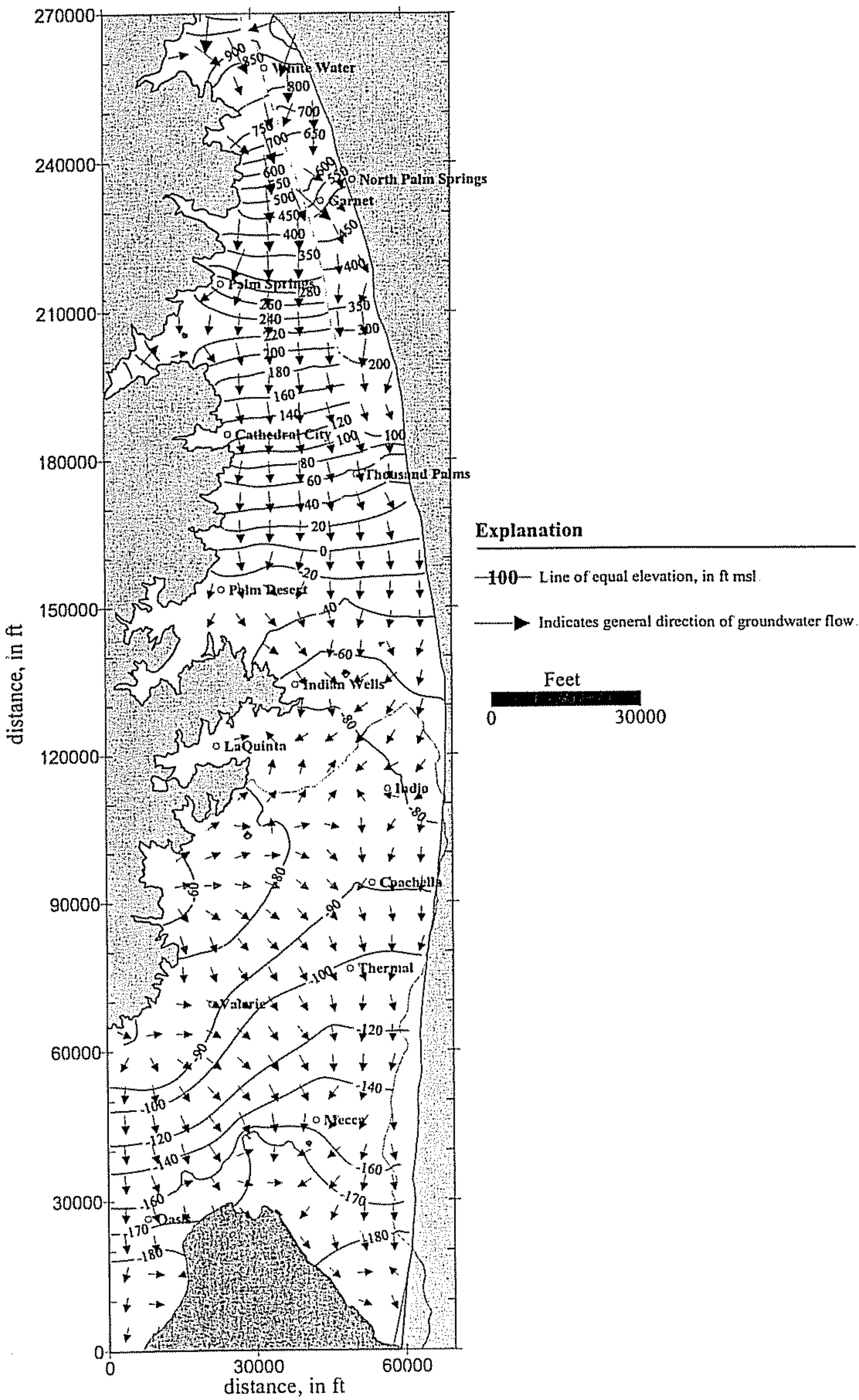
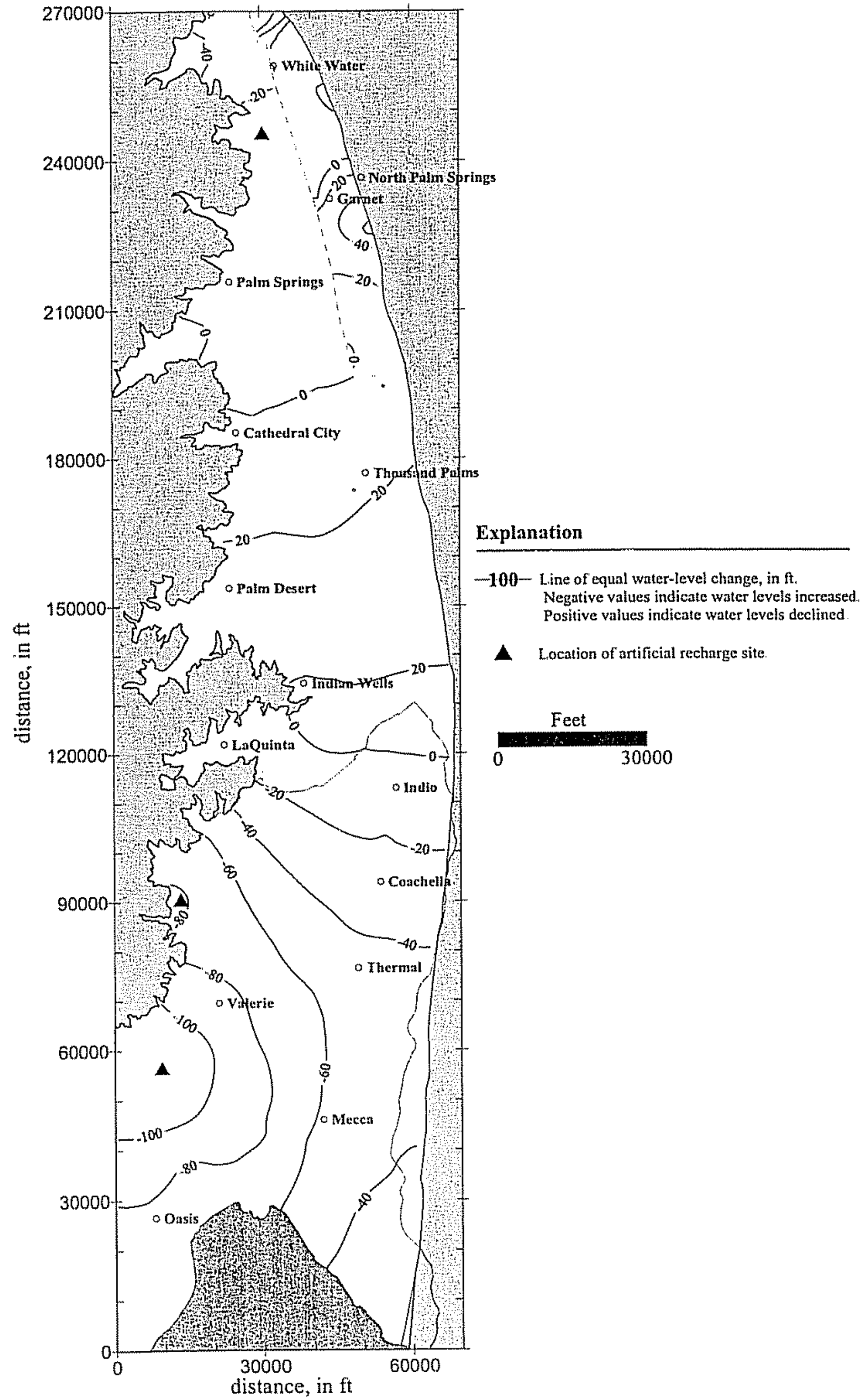


Figure 37.
Alternative 4 potential water-level difference in layer 4, 1999-2035.



8 ACKNOWLEDGEMENTS

Long interested in the management of groundwater resources in Coachella Valley, the late Harvey O. Banks was key in developing the plan for building a groundwater model of the entire valley. Thomas E. Levy, general manager and chief engineer at CVWD, supported the project from the start; CVWD engineers, especially Robert Robinson and Steve Robbins, provided raw data and knowledge of CVWD's data collection methodologies, as well as local information concerning management of water in Coachella Valley. Carlos Perez at CVWD assisted with digitizing the base map. By cooperative study, JMLord, Inc. developed the estimates of crop acreage, crop water use and irrigation efficiency used in determining agricultural groundwater pumpage and return estimates for the model. Eric Reichard at USGS provided raw data from previous USGS modeling studies. Gary Weissmann and Robert Taylor at U.C. Davis and Matt Hacker at Montgomery Watson assisted in the hydrostratigraphic analysis.

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Coachella Valley Groundwater Model

Peer Review Report

Prepared for:

Redwine and Sherrill
1950 Market Street
Riverside, California 92501-1704

September 18, 1998

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1 INTRODUCTION

1.1 PEER REVIEW PANEL

The peer review panel consisted of an engineer and two hydrogeologists well versed in groundwater modeling:

Steve Larson, S.S. Papadopulos & Associates
Jim Mercer, HSI GeoTrans, Inc.
Irwin Remson, Stanford University (retired)

In the 1950s, Irwin Remson helped develop unsaturated-flow theory using theoretical numerical methods coupled with field verification for the U.S. Geological Survey at Seabrook Farms, New Jersey. In the 1960s, as a Professor of Civil Engineering and Mechanics at Drexel Institute of Technology, he helped extend these methods to saturated flow using computer applications. Since 1968, as Morris Professor of Earth Sciences at Stanford University, Dr. Remson has merged numerical methods and mathematical programming with "simulation-management models." These have been used to optimize the management of groundwater flow and contaminant transport problems and are being described in a book in progress. Dr. Remson has furthered the integration of environmental sciences with city and regional planning, which provides a vehicle for constructive environmental work.

As a groundwater hydrologist with S.S. Papadopulos for the past 18 years, Steve Larson has conducted numerous projects investigating and evaluating groundwater resource and contamination problems. Many of these projects utilized modeling analyses to quantitatively evaluate various components of the problems. Prior to his career in private consulting practice, Mr. Larson spent nine years as a hydrologist with the Water Resources Division of the U.S. Geological Survey. During his tenure there, he conducted research into the development and use of groundwater models for evaluating a variety of groundwater problems.

Dr. James W. Mercer was with the U.S. Geological Survey for eight years, during which time he developed groundwater flow and heat transport models. Upon leaving the U.S.G.S., he applied models to hazardous waste sites and received the Wesley W. Horner Award for groundwater modeling at Love Canal. He is the Executive Vice President of HSI GeoTrans, which he co-founded in 1979. Resumes are included in Appendix A.

1.2 PEER REVIEW CHARGE

The Coachella Valley Water District (CVWD) has commissioned the construction of a groundwater model by Dr. Graham Fogg of the University of California at Davis. The overall purpose of the groundwater model is to aid the District in establishing a management plan for the water resources of the Coachella Valley. Accordingly, the goals of the peer review process are to:

- Given the conceptual model, numerical model construction and performance in historical simulation, comment on model reliability.
- Evaluate suitability of model to simulate prevention of intrusion of groundwater from the Salton Sea and stabilization of groundwater levels in response to management options of artificial recharge.
- Recommend changes, if needed, to achieve the above.

1.3 PEER REVIEW PROCESS

The peer review process consisted of review of background materials and participation in three meetings with the groundwater modeling team. The peer review was an iterative process, as the model was not complete at the beginning of the review period. As a result, there was time for peer review comments to be considered and the modeling approach modified, as appropriate. The first meeting occurred on August 11-12, 1997, in Coachella, California, at the District office. Preceding the meeting, an air tour of the District was conducted. The second meeting occurred on September 9-10, 1997, in Denver, Colorado. At both of these meetings, modeling results were presented and discussed. The third peer review meeting took place on February 26-27, 1998. The focus of this meeting was the peer review panel's comments and observations as they pertained to the model calibration.

As indicated, the review meetings included the peer review panel as well as the modeling team. This team consisted of:

Graham Fogg, University of California, Davis
Eric LaBolle, University of California, Davis
Gerald O'Neill, WellWare

They were assisted by:

Steve Robbins, CVWD
Robert Robinson, CVWD
Dave Ringel, Montgomery Watson, Inc.
Joe Hall, Hall, Pitts & Associates (now Water Consult)
Tom Pitts, Hall, Pitts & Associates (now Water Consult)

One of the strengths of the Coachella Valley groundwater model is in the nature of the team that put it together. The team includes expertise in modeling as well as geology, hydrology and water management. The team leader, Professor Graham E. Fogg, has successfully modeled very large and very complicated hydrogeologic systems. Members of the peer review panel have had extensive discussions with the modeling team over specific details. It is apparent that the team has spent months studying such details, evaluating the hydrogeology and trying different scenarios on the developing model. Thus, the developing model was used to back up the analyses by assessing the consistency and effects of various hydrological and geological interpretations.

2 REVIEW OF CONCEPTUAL MODEL

2.1 PROBLEM DEFINITION

The Coachella Valley Water District is evaluating numerous water resource issues and the effects of various alternatives for managing groundwater in the Coachella Valley. The issues include artificial recharge, reductions in pumpage, sustainable groundwater levels and quality, prevention of potential saline water intrusion from the Salton Sea, prevention of potential land subsidence, conservation of available water resources and environmental effects, among others. The purpose of the Coachella Valley groundwater flow model is to assist in the appraisal of the alternatives and their benefits and impacts. Additional model objectives are to serve as a groundwater data base and as an analytical tool for evaluating geologic and hydrologic concepts.

The Coachella Valley hydrologic system is large and complicated. Geologically, the Lower Valley contains multiple aquifer zones and consists of a semiperched aquifer, an upper aquifer of Older Alluvium, an aquitard, and a lower aquifer of Ocotillo Conglomerate. These merge into a single aquifer in the Upper Valley as the finer-grained units feather out. Faults traverse the Valley and structural hills, ridges and a topographic bench within the Valley disrupt the groundwater flow systems. The valley topography varies from about 1,200 feet at the upper end to about 200 feet below sea level at the Salton Sea.

Hydrologically, boundary conditions vary from the San Gorgonio Pass to the north, where water enters via the San Gorgonio River and its underflow, to the Salton Sea to the south, with the attendant concerns about saline water intrusion. The Valley is generally bounded by crystalline mountain ranges, and various streams and seepages cross the boundaries. Surface water enters via the Whitewater River, various other creeks and seepages, and importations from the Colorado River canals. Evapotranspiration occurs from water surfaces, phreatophytes, irrigated agriculture and arid-zone vegetation. Water is discharged from the aquifers by wells for irrigated agriculture, municipal and domestic use and fish farming as well as by evapotranspiration and agricultural drains. Water enters the various aquifers by natural and artificial recharge of streamflow, imported water and irrigation return.

2.2 USE OF PREVIOUS STUDIES

The Coachella Valley groundwater modeling effort has made good use of previous modeling studies in the area. These modeling studies were performed by the U.S. Geological Survey, focusing on the Upper Coachella Valley. The studies include Tyley (1974), Swain (1978) and Reichard and Meadows (1992). The present study has made use of knowledge gained in the Upper Coachella Valley as a result of these previous modeling studies (e.g., specifying boundary conditions), and has expanded the study area to include the Lower Coachella Valley. The present modeling effort has also expanded the previous work, which was two-dimensional, to a three-dimensional model. In expanding the model, use was made of data in District files as well as data in CDWR (1964 and 1979) which are discussed below.

2.3 AVAILABLE DATA

A large amount of data was available to the modeling team. One of the benefits derived from the modeling effort was organizing the data into a format that is useful to understanding the Valley hydrogeology. Data and source information used in the modeling effort are summarized below:

- Land surface elevation: U.S.G.S. digital elevation model (DEM).

- Geologic characterizations: CDWR (1964 and 1979); available electric and drillers log data.

- Precipitation: Monthly precipitation records were downloaded from the National Climatic Data Center web site (http://www.ncdc.noaa.gov/coop-precip.html) for the gauges in the vicinity of the study area. Supplemental data for selected gauges were obtained from microfiche precipitation records from the California Department of Water Resources (DWR, *California Rainfall Summary*, July 1981).

- Transmissivity: Field tests, specific capacity, hydrostratigraphy, U.S.G.S. calibration (Upper Valley).

- Storativity/Specific Yield: Field tests, hydrostratigraphy, U.S.G.S. calibration (Upper Valley).

- Pumpage (agricultural, municipal, golf courses, fish farms): Consumptive use method, meters, U.S.G.S. modeling (Upper Valley).
- Return Flow: Consumptive use method, previously assumed returns.

- Ephemeral Stream Recharge: Rainfall-runoff data and analysis, previous U.S.G.S. work.

- Drains: CVWD monitors the flow in each drain that flows directly into the Salton Sea and the Coachella Valley Storm Water Channel (CVSWC). These flows are measured once per month using current meters when there are no storm flows, so they should be indicative of base flow. Because regulatory water is released into the drainage system, CVWD adjusts the daily metered flows by subtracting that day's regulatory flows, multiplying by the number of days in the month, and adding back the total monthly regulatory flows. Flow measurements for individual drains discharging into the CVSWC are not available.

- ET from Undeveloped Land: Drain database, previous work in the Southwest.

- Water Levels: CVWD records.

2.4 DATA UNCERTAINTIES

Although a large database was developed by the modeling team, data gaps and data uncertainties exist, as they do in any modeling study. Data uncertainties for the Coachella Valley include:

- The geological data show aquifers and a confining bed in the multiple aquifer zones; however, the hydrogeological system is more complex, consisting of interbedded intervals of sand, gravel, silt, and clay rather than distinct, relatively uniform zones.

- Water-level data depend on the elevation of the measurement point. The District has surveyed some of the wells; however, many well elevations were estimated from U.S.G.S. topographic maps. Consequently, the uncertainty in measured water levels at some wells could be as great as 10-20 feet. In addition, water-level data for the upper aquifer in the Lower Valley are sparse.

- For the Upper Valley, municipal and domestic pumpage prior to 1974 was based on the U.S.G.S. studies. Between 1974-1979, no data on municipal and domestic pumpage are available for the Upper Valley. After 1979, municipal and domestic pumpage was metered in the Upper Valley. For the Lower Valley, prior to 1980, pumpage was estimated from census data; after 1980, some actual pumpage data were available.

- Initial conditions are based on water-level data from 1936, when well data were sparse.

3 REVIEW OF NUMERICAL MODEL

The model application to the Coachella Valley groundwater system followed standard practice according to guidance in ASTM D5447-93.[1] Components of the numerical models are discussed below.

3.1 CODE SELECTED

The code selected for the Coachella Valley groundwater model is MODFLOW. This code was first distributed in 1984 (McDonald and Harbaugh, 1984) with updated documentation in 1988 (McDonald and Harbaugh, 1988). The latest U.S.G.S. version is called MODFLOW-96 (Harbaugh and McDonald, 1996 a & b). This is a publically-available code developed by the U.S. Geological Survey. As a result of the source of the code and the length of time the code has been in use, MODFLOW has widespread acceptance in both scientific and legal arenas. MODFLOW also has appropriate code features for simulating the groundwater system in the Coachella Valley. For these reasons, the peer review panel agrees with the choice of the MODFLOW code.

The panel suggested one code modification. In order to avoid the layer-rewetting option, which can be unstable, MODFLOW could be modified such that the rewetting option is stabilized.

3.2 GRID AND LAYERS

The model consists of four layers with a horizontal node spacing of a uniform 1,000 feet. The 1,000-ft spacing is adequate for the regional-scale model. Four layers were required to represent the multiple aquifers in the Lower Valley. Where these multiple aquifers are present,

- layer 4 represents the lower aquifer,
- layer 3 represents an aquitard zone,

[1]American Society for Testing and Materials (ASTM) D5447-93, Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem.

- layer 2 represents an upper aquifer, and
- layer 1 represents the "semi-perched" aquifer in the Lower Valley.

The grid has been aligned with the valley and is oriented in a northwest-southeast direction. The combination of grid and layers results in 45,288 active nodes. The vertical spacing is as follows: (1) layer 4 is generally about 1,000 feet thick, (2) thickness of layers 3, 2, and 1 vary based on geological characterizations in CDWR (1964 and 1979). Within the multiple aquifer zones, layer 3 is approximately 150 feet thick and layer 2 is approximately 225 feet thick. Layer 1 is approximately 100 feet thick in the semiperched zone. The peer review panel concurs with the grid and layers. A feature the panel thought should be captured by the thickness of layer 4 is the bedrock ridge that exists at the San Gorgonio Pass. The model bottom elevations were adjusted to account for this bedrock ridge.

3.3 BOUNDARY CONDITIONS

The active area of the model is bounded by San Gorgonio Pass up gradient (northwest) and the Salton Sea down gradient (southeast), the San Jacinto and Santa Rosa Mountains and associated canyons along the Southwest margin, and the San Andreas and Banning Faults along the northeast margin. The base of the aquifer system is assumed to be the depth to which fresh water circulates and is assumed to be an impermeable boundary (no flow). The upper boundary is the water table; processes effecting this boundary include recharge, drains and evapotranspiration, which are discussed in another section. Each boundary condition is discussed below.

> <u>San Gorgonio Pass</u>: A time-variant specified head boundary condition was used to model inflow from the San Gorgonio Pass area. The specified head was based on measured values at a well located near the pass. The MODFLOW Time-Variant Specified Head Package (Leake and Prudic, 1991) was used to simulate the boundary.

> <u>Banning and San Andreas Faults</u>: These two faults form the northeastern boundary of the Coachella Valley groundwater basin. The Banning Fault is considered to be an imperfect barrier to groundwater movement based on significant groundwater level and quality differences across the fault, and the presence of springs, cienegas and dense vegetation in canyon oases along the strike of the fault. Tyley (1971) estimated flow across the Banning Fault into the Garnet Hill Subbasin to be 2,000 acre-ft per year. This low value was assigned uniformly to specified flux nodes along the trace

of the Banning Fault in the model. South of the Banning Fault, the San Andreas Fault is considered a barrier and is treated as a no-flow boundary in the model.

Mountain Fronts: For the purpose of groundwater modeling, the volume of tributary inflow of surface and groundwater from the mountain watersheds was estimated from rainfall-runoff curves that were developed for six of the watersheds for which sufficient data were available. The average annual tributary inflow to the study area during the 61-year model calibration period was estimated for each of the mountain watersheds, using a method similar to that employed by the California Department of Water Resources in a previous study in the Coachella Valley (DWR, 1964). Using this approach, annual subsurface inflow reaching the model boundary at nodal locations representing twenty-four watersheds was specified. Also, see discussion on Sources/Sinks.

Salton Sea: On the southeastern boundary of the Coachella Valley, fresh groundwater mingles with dense saline groundwater underlying the Salton Sea. The model simulates this interface using a sharp-interface assumption, where the interface is represented as a vertical no-flow boundary under the Sea (layers 2, 3 and 4). Specified-head conditions are applied to layer one along the perimeter of the Sea, where equivalent freshwater heads are determined.

The panel agrees with the treatment of all boundary conditions with the exception of that for the Salton Sea. The no-flow boundary in layers 2, 3, and 4 with nearby pumping (e.g., Kent Seafarms) was thought to result in an overestimation of drawdown. It was suggested that alternative boundary conditions be considered, such as maintain specified head (time dependent) in layer 1 for all nodes within the Sea and making the nodes active in layers 2, 3, and 4 under the Sea. The new Salton Sea boundary condition was implemented and proved to be satisfactory. In addition, the location of the Salton Sea boundary condition was adjusted based on more accurate maps. This eliminated drains being inundated in the model where previously the Salton Sea had inappropriately overlayed drains in the model.

3.4 INITIAL CONDITIONS

The simulations begin at the earliest time when sufficient water-level and pumpage data were available. This time period corresponds to 1936, for which time the "initial" observed head distribution is used. This starting point is consistent with previous modeling studies performed by the U.S.G.S. (see e.g., Tyley, 1971). Based on the response of some wells in the semi-perched zone, the panel believes that the estimated water levels for 1936 may be too high in certain locations. The initial conditions were revised such that initial heads in the semi-perched zone were not above land surface.

3.5 PARAMETERS

Fifty pumping tests were analyzed for **transmissivity (T)** using the Cooper-Jacob method. These results were combined with results from specific capacity tests and results from the U.S.G.S. calibration. Transmissivity was then converted to **hydraulic conductivity** (K) by dividing by screened-interval thickness of the appropriate well. These values were further modified using the percent of coarse-grained sediments in the stratigraphic column. These data were used to estimate nodal K values that were modified appropriately during the calibration process.

Special consideration was given to the Garnet Hill Fault, which is located about 1½ miles south of, and generally parallel to, the Banning Fault. DWR (1964) suggested that the fault has not displaced Recent alluvium, but is effective as a barrier to groundwater flow below depths of 100 feet, based on water-level measurements at the fault. The Garnet Hill Fault is represented as a barrier and simulated using the Horizontal Flow Barrier Package (Hsieh and Freckleton, 1993). The conductance across this fault in layer one is a parameter that was determined as part of the calibration process.

Spatially variable **specific yield (S_y)** was assigned in the Upper Valley based on the U.S.G.S. model calibration. Other storage values were assigned based on field test data and well logs. Estimates of this parameter were improved during the calibration process.

The peer review panel suggested sensitivity analyses of certain parameters for various layers. In particular, **specific storage (S_s)** values may need adjustment downward, particularly in thin layers 2 and 3. Also, the **vertical hydraulic conductivity (K_v)**, a calibration parameter, for the confining bed (layer 3) may be too low. A sensitivity analysis of S_s and K_v was performed that lead to adjustments in these parameters.

Based on discussions with the modeling team, layer 1 may be better connected across the Garnet Hill Fault. Also, based on the depositional history of the basin, fine sediments were deposited in the low part where the Salton Sea is located. Therefore, it is expected that K will decrease gradationally toward and under the Salton Sea. This gradation of K near the Salton Sea was implemented in the calibrated model.

In addition, near the San Gorgonio Pass, the Whitewater River channel contains coarse-grained sediments that are expected to have higher K than the surrounding sediments. This feature was added to the model by increasing the K at locations of the Whitewater River channel in the northern part of the Upper Valley. This channel also may provide a connection between the upper and lower aquifers where coarser-grained sediments are present in the Lower Valley.

3.6 SOURCES/SINKS

Sources and sinks considered include the following:

3.6.1 TRIBUTARY RECHARGE

Inflow from mountain watersheds is generally applied as described in the section on boundary conditions. During the calibration process, estimates of subsurface inflow from the Whitewater River canyon were improved. Tributary recharge includes subsurface inflow from mountain watersheds and percolation of surface water. For dry years, this flux is applied at the model boundary. For wet years (greater than 1,000 ac-ft of Whitewater River flow at Indio), recharge is distributed along major tributaries according to a simple river routing model. Estimates of the distribution of recharge along the Whitewater River were improved during calibration to better define infiltration above the spreading basins. In addition, estimates of recharge from diversions at Snow, Falls, and Chino Creeks in Palm Springs were added to the model.

3.6.2 PRECIPITATION

Precipitation on the valley floor is about 4.5 inches per year. This is generally consumed by evapotranspiration. The resulting recharge for groundwater modeling purposes is assumed to be zero.

3.6.3 PUMPAGE

Pumpage was assigned to the model block and layer where the well and screen interval were located. During the course of the review, a question was raised concerning the pumpage due to fish and duck farms in the Lower Valley and to which layer of the model this is assigned. The peer review panel recommended this pumpage be checked and correctly assigned, if necessary. Also, the time period 1974-1979 was missing pumpage data, and had to be estimated; for the Point Happy area, the pumpage may have been underestimated. The peer review panel agreed with the modeling team that this pumpage be checked and corrected, if necessary. Following this recommendation, improvements were made to both the pumpage and return flow data bases. These improvements included: (a) fish farm pumpage reallocated to upper and lower aquifers, (b) improved estimates of municipal/domestic and golf course pumpage and returns (particularly 1968-84 in the Upper Valley), (c) added estimates of returns from Palm Springs Waste Water Treatment Plants, and (d) added domestic on-farm pumping. In addition, the model stress periods were revised to one year after 1950.

3.6.4 DRAINS

The drains are treated as a boundary condition in the model. Agricultural drains were installed to reduce high water-table conditions in the Lower Valley. The first farm drainage systems were installed in February 1950. The land containing drains increased rapidly throughout the 1950's, and currently over 37,000 acres of farm land have drains installed. Drain depth varies from approximately 6 to 10 feet. Drains are simulated in MODFLOW by specifying their location, elevation and hydraulic conductance for each model stress period. The drain depth was uniformly assigned as 10 feet below ground surface and a hydraulic conductance of 1,000 ft^2/d was used. The peer review panel observed that drain fluxes were high and suggested use of a shallower drain depth, perhaps 6 feet. Further sensitivity work on this parameter was suggested. Following this recommendation, drain depths were adjusted in the model. In addition, estimates for drain conductance were improved during the calibration process.

3.6.5 EVAPOTRANSPIRATION (ET)

The ET package in MODFLOW was used to simulate ET on undeveloped lands. For this package, the following were specified: an extinction depth of 8 feet and a maximum ET rate of 36 in/y. Depending on the final drain specifications, the peer review panel believed

ET parameters may need to be modified. As a result of this recommendation and the calibration process, the ET rate and extinction depth were changed.

4 REVIEW OF MODEL CALIBRATION

A 61-year calibration period from 1936 to 1996 was used in the model calibration. Peer review interaction occurred during the calibration process. Sensitivity studies were used appropriately in the calibration process. Changes in parameters were consistent with hydrogeological data. Calibration targets included measured hydraulic heads and measured or estimated water fluxes (water budgets). The peer review panel believes the calibration targets are appropriate. Using fluxes, such as drain flows, reduces nonuniqueness in the calibration. Hydraulic head comparisons were made using time-series plots, potentiometric surfaces, and scatter diagrams. Water flux comparisons were made via a water balance. In general, trends in simulated hydraulic head compared well with measured values.

5 REVIEW OF SCENARIO SIMULATIONS

The peer review panel has reviewed the management options under consideration by the Water District. These alternatives included:

- Alternative 1 - Base case
- Alternative 2 - Adjudication and groundwater pumping restrictions
- Alternative 3 - Manage demand and maximize local resources
- Alternative 4 - Direct groundwater recharge
- Alternative 5 - Source substitution
- Alternative 6 - Combination alternative

The six different water management plan alternatives were simulated to the year 2015. Results of the scenario simulations primarily were evaluated in terms of (1) sustainability of groundwater levels and (2) maintenance of net groundwater discharge to the Salton Sea. Based on the review, the panel believes the groundwater model is appropriate and adequate to evaluate the various alternatives.

6 SUMMARY AND CONCLUSIONS

With such a large complex hydrologic system and with uncertainties in the data and understanding, one may question the model validity. Fortunately, most of the model groundwater level predictions are within 10 or 20 feet of measured levels. This is excellent calibration, considering the 1200 foot topographic change from the upper to lower boundaries. In addition, restudy of the hydrology and geology and sensitivity analysis are being used to analyze local problem areas. Furthermore, the model is being evaluated over two extensive databases. One is the historical database, and the other is the spatial database, and the model predictions hold up well areally and historically.

It is apparent that the overall model is valid and that continued study should be restricted to specific local problems. Changes in these local areas will not affect the overall model. The model may be used in conjunction with the evaluation and comparison of management scenarios. Additional model changes in discrete areas will not affect the determinations of overall management benefits and impacts. The peer review panel believes that the model is suitable to aid in making management decisions concerning water development in the Coachella Valley.

Specific recommendations made by the peer review panel are provided throughout this report.

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APPENDIX A - Resumes

STEVEN P. LARSON
Groundwater Hydrologist

Education	Master of Science in Civil Engineering, 1971, University of Minnesota, Minneapolis, Minnesota Bachelor of Science in Civil Engineering (with high distinction), 1969, University of Minnesota, Minneapolis, Minnesota
Professional Societies	Association of Ground Water Scientists and Engineers American Institute of Hydrology Chi Epsilon
Awards & Honors	American Society of Civil Engineering Student Award, 1969 Civil Servant of the Year, U.S. Geological Survey, 1974 U.S. Geological Survey Incentive Award, 1974
Registration	Professional Hydrologist - Ground Water (American Institute of Hydrology)

Professional Experience

April 1980 to present

S. S. Papadopulos & Associates, Inc., Environmental & Water-Resource Consultants, Bethesda, Maryland. Executive Vice President. As a senior principal of the company, assists in the management of the company. Primary responsibility is to conduct and manage projects dealing with a wide variety of environmental and water-resource issues. During his many years at SSP&A, he has been involved in numerous projects covering a wide spectrum of technical, environmental, and legal issues including;

a) Site evaluations such as remedial investigations, feasibility studies, engineering evaluation/cost analyses, or remedial action plans at CERCLA and other waste disposal sites including the Stringfellow site in California, the FMC Fridley site in Minnesota, the Chem Dyne site in Ohio, the Conservation Chemical site in Missouri, the Hardage-Criner site in Oklahoma, and the Hastings site in Nebraska.

b) Environmental impact evaluations including the effects of water development for proposed coal slurry operations in Wyoming, the effects of in-situ mining for trona minerals in Wyoming, and the effects of groundwater development on shallow-water table conditions in South Dakota.

c) Water-supply development evaluations including potential impacts of salt water intrusion on water supply development in Oman, Portugal, and Florida and potential impacts of development of

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Groundwater Hydrologist

April 1980
to present

(Continued)

power plant cooling water on groundwater and surface water in Wyoming.

d) Evaluations of mining operations regarding permitting, licensing, and environmental issues including, coal mining in Wyoming, Montana, and Arizona, copper mining in Montana and Utah, trona mining in Wyoming and uranium mining in New Mexico.

e) Evaluations of water-rights permitting and adjudication in New Mexico, Texas, Colorado, Kansas, Wyoming, Nebraska, Arizona, and Idaho.

f) Evaluations of discharge to groundwater or other RCRA-related issues including chemical-manufacturing waste disposal in Wyoming, Virginia, and New York; septic tank effluents in Maryland; and radioactive waste disposal in New Mexico and Missouri.

g) Evaluations of groundwater contamination at CERCLA and other waste-disposal sites including the Love Canal site in New York, the Savannah River Plant site in South Carolina, the Tucson Airport site in Arizona, the Ottati & Goss site in New Hampshire, the Martin-Marietta site in Colorado, and the Western Processing site in Washington.

h) Environmental audits, groundwater monitoring plans, and other environmental investigations at various locations including the Oaks Landfill in Maryland, the FMC Carteret facility, a former IBM facility in Indiana, and the Insilco site in Florida.

He has served as an expert witness in the field of groundwater hydrology, including chemical fate and transport, in numerous administrative and legal forums. These projects include;

a) CERCLA, RCRA, or related litigation concerning contamination of soil and groundwater at sites or facilities located in California, Kansas, Missouri, Oklahoma, Tennessee, Montana, Florida, Iowa, and Nebraska.

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Groundwater Hydrologist

April 1980
to present

(Continued)

b) Toxic tort, property damage, or liability litigation associated with contamination of soil and groundwater at sites or facilities located in New York, Tennessee, Texas, Virginia, Ohio, and other states.

c) Insurance recovery litigation associated with contamination at a variety of sites or facilities located in numerous areas for commercial clients such as General Electric, FMC Corporation, Upjohn, AT&T, Rohr Industries, Beazer East/Koppers, North American Phillips, DOW Chemical, Occidental Chemical, and Southern California Edison.

d) Water-rights permitting litigation and water adjudication including cases in New Mexico, Colorado, and Arizona, as well as interstate river compact disputes involving the states of Kansas, Colorado, Wyoming, and Nebraska.

e) He has also served as a mediator/arbitrator in cases involving allocation of responsibility for groundwater contamination and impacts of groundwater development.

Some recently completed or current projects where he has had primary responsibility for the project include;

a) The Stringfellow site near Riverside, California. Mr. Larson serves as the principal technical advisor on groundwater issues to the Pyrite Canyon Group, which oversees investigations and remedial activities sponsored by a group of responsible parties. In addition to providing consultation on many technical issues, Mr. Larson has designed and evaluated several investigative and remediation programs. He has represented the responsible parties as a technical spokesperson in numerous workshops and technical seminars or meetings with regulatory agencies and other interested parties. He has also prepared key technical documents to support the decision-making process and progress toward a final record of decision.

b) Kansas v. Colorado, an original action in the Supreme Court of the United States. Mr. Larson serves as part of a team of technical advisors for the State of Kansas in its litigation with Colorado over violations of the Arkansas River Compact. He assisted Kansas in obtaining a finding of compact violation regarding the pumping of groundwater from wells along the river valley in Colorado. He is

TABLE 1. AVERAGE WATER USE, 1995 (TAFY)

HYDROLOGIC REGION	URBAN	WATER USE AGRICULTURAL	TOTAL
South Coast	4,340	784	5,124
Colorado River	418	4,118	4,536
Total	4,758	4,902	9,660

SOURCE: DWR, Bulletin 160-98

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Groundwater Hydrologist

April 1980 to present

(Continued)

continuing to serve Kansas as a technical expert as the case moves into subsequent phases involving quantification of depletions, assessments of damage, and future compliance by Colorado.

c) The Far-Mar-Co Subsite of the Hastings Superfund Site in Hastings, Nebraska. On behalf of a small group of responsible parties including Morrisson Enterprises, Dutton-Lainson, and the City of Hastings, Mr. Larson supervised the preparation of an engineering evaluation/cost analysis (EE/CA) to support implementation of a removal action to address groundwater contamination. He worked with regulatory agencies to gain approval of the EE/CA and progress toward design and implementation of the removal action. Previously, on behalf of Morrisson Enterprises, he supervised completion of a remedial investigation and a feasibility study for the subsite which focused on contamination by carbon tetrachloride and ethylene dibromide.

d) Insurance recovery litigation on behalf of Koppers Company, Inc. Mr. Larson served as an expert witness in a trial against insurance carriers involving a number of former Kopper's sites and facilities. He testified regarding the nature and occurrence of soil and groundwater contamination at the various sites and facilities and assisted Koppers in obtaining a favorable verdict in the case.

January 1975 to April 1980

U.S. Geological Survey, Water Resources Division, Northeastern Region, Reston, Virginia. Hydrologist GS-12, (1/75-9/77), Hydrologist GS-13 (9/77-4/80). Originated, planned and conducted research in the development of numerical simulation models and techniques for the analysis of a variety of problems related to ground- water systems.

Applied the developed models to actual field situations for verification and further refinement and documented these models in a manner suitable for use by others. Served as coordinator and instructor for training courses on groundwater simulation models and methodologies conducted by the Division. Provided primary technical assistance to many ground-water projects conducted by District offices and reviewed reports on the technical aspects of these projects. Participated in and represented the U.S. Geological Survey in national and international meetings. Conducted groundwater studies of national and regional interest and participated in, or was detailed to overseas projects conducted or managed by other U.S. agencies and the World Bank.

STEVEN P. LARSON
Groundwater Hydrologist

December 1971 to January 1975	U.S. Geological Survey, Water Resources Division, Minnesota District, St. Paul, Minnesota. Hydrologist GS-9 (12/71-10/73), Hydrologist GS-11 (10/73-1/75). Served as Project Chief and participated in studies involving the evaluation of groundwater resources, the assessment of stream-water quality and the analysis of surface-water - groundwater relationships in various parts of Minnesota.
July 1971 to December 1971	U.S. Geological Survey, Water Resources Division, National Training Center, Denver, Colorado. Hydrologist GS-9. Participated in an extended training program providing in-depth training on both office and field techniques for the collection and the analysis of data and the conduct of surface water, groundwater and water-quality studies.
July 1969 to July 1971	St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota. Research Assistant. Assisted in the development and operation of an ~~urban runoff model to predict sewer flow~~ distribution for the Minneapolis - St. Paul Sanitary District. Assisted in runoff prediction studies for St. Paul and had major duties in a project to survey and summarize computer programs used in water resources engineering.

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HSI GEOTRANS
A TETRA TECH COMPANY

JAMES W. MERCER, PH.D., P.G.
EXECUTIVE VICE PRESIDENT/PRINCIPAL HYDROGEOLOGIST

Education:

Ph.D., Geology, University of Illinois, 1973
M.S., Geology, University of Illinois, 1971
B.S., Geology, Florida State University, 1969
A.S., Gulf Coast Jr. College, Panama City, Florida, 1967

Professional Experience:

HSI GEOTRANS, Sterling, Virginia, (1997 - Present), *Executive Vice President, Research & Development, Principal Hydrogeologist*
GEOTRANS, INC., Sterling, Virginia, (1979 - 1996), *President and Principal Hydrogeologist*
U.S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION, Reston, Virginia, (1971-1979), *Hydrologist*

More than 27 years of experience specializing in all phases of geohydrologic transport analysis including groundwater flow, heat and solute transport in porous media for a wide range of applications such as aquifer resource analysis, aquifer thermal storage, geothermal energy development, radioactive waste storage, seawater intrusion, and hazardous waste problems. Experience in the following U.S. EPA programs: RCRA, CERCLA/SARA, UST, and UIC. Involved in the conduct of both RI/FS and RCRA FI/CMS. Management responsibilities include supervision of approximately 50 professionals and serving as principal investigator on several contracts. Daily project work involves overseeing data collection, data management, and analysis. Projects involve a variety of chemicals including organics, metals, and radionuclides. Processes considered include advection, hydrodynamic dispersion, diffusion, biodegradation, multiphase flow, dissolution, and volatilization in fractured and porous media. Various tasks include modeling, training, and expert witness testimony.

Relevant Project Experience:

U.S. EPA, Ada, Oklahoma - Project Manager for information transfer programs (workshops, demonstrations, seminars); author of guidance documents (The U.S. EPA Handbook for the *Site Characterization of Dense Non-Aqueous Phase Liquids*, and *The Basics of Pump-and-Treat Groundwater Remediation Technology*); functioned as the off-site support team for groundwater issues; contributed to the Remedial Operations and Performance Evaluation Methodology; and provided technical training on groundwater model applications.

U.S. Nuclear Regulatory Commission - Project Manager for benchmarking of computer codes used for the evaluation of high-level radioactive waste disposal repositories for the U.S. Nuclear Regulatory Commission. Directed the review of literature, selection of codes, code benchmarking, and technology transfer on the use and limitations of the computer models. Also assisted in the development of an earth sciences database for storage and retrieval of data reported for the high-level radioactive waste repositories. To create the database, more than 29,000 measurements of 240 parameters were extracted from a broad base of source references. The data are comprised of hydrogeologic, geomechanical, geochemical, and stratigraphic parameters and their accompanying descriptive information.

Columbus Air Force Base, Mississippi - Principal Investigator for TVA MADE and MADE-2 saturated zone groundwater transport studies. Performed site visits to review field activities and make independent observations on technical activities related to the field tracer experiment. Provided independent analysis on field activities and data acquired during the course of the studies.

Yucca Mountain, Nevada - Served as part of the U.S. DOE Peer Review Team for Unsaturated Zone Hydrology. Also served as consultant to U.S. DOE on the conduct of RI/FS projects at nuclear test facilities including the Nevada Test Site.

Dry Cleaner, Pensacola, Florida - On behalf of a client named as a PRP, served as expert witness in hydrogeology, dense non-aqueous phase liquids (DNAPLs), and fate and transport of chemicals in a subsurface environment. Reviewed and discussed site hydrogeology, contaminant transport, and capture zone analysis of municipal supply wells, and discussed other PCE sources in downtown Pensacola. Analyses performed included graphic analysis of three-dimensional aspects of the plume and flow system relative to water supply wells; estimate of impacts on flow system due to pumping of water supply wells; and estimates of plume development with time from a historical perspective.

Hazardous Waste Site, Pittsburgh, Pennsylvania - Principal Investigator for data review and groundwater modeling to evaluate whether a dissolved benzene plume emanating from an abandoned hazardous waste site was undergoing intrinsic remediation. Performed an initial evaluation, recommended collection of additional geochemical data, and implemented three-dimensional groundwater flow modeling to evaluate the effectiveness of a capture scenario. Data collected during this investigation provided additional evidence that intrinsic remediation of benzene was occurring.

Hazardous Waste Site, Jacksonville, Florida - Principal Investigator for site characterization and pilot testing, design, and construction of air sparging/SVE remedial system at a site contaminated with chlorinated solvents. Assisted in construction management and startup of the system, incorporating groundwater pumping and soil vapor extraction of three dual extraction wells and 12 air sparging points within the pumping well cone of depression.

Former Dry Cleaners, Westminster, California - Principal Investigator for evaluation of PCE contamination related to a former dry cleaning operation. Evaluated site hydrogeology, PCE distribution, and transport modes, including dense non-aqueous phase liquid migration, vapor phase migration, and aqueous phase migration. Served as expert consultant to assist with evaluating the timing and nature of releases in an effort to avoid litigation.

Former Dry Cleaner, Warrington, Florida - Principal Investigator for evaluation of PCE impacts that was found in a water supply well and traced to a former dry cleaner. Represented a shopping center owner against the former dry cleaner. Reviewed site hydrogeology and contaminant distribution, along with site history, which included a solvent spill. Data analysis indicated the presence of dense non-aqueous phase liquid PCE. Analyzed contaminant transport, including sewer lines providing a preferred flow path, and vertical migration due to pumping in the area.

Martin Marietta, Paducah Gaseous Diffusion Plant, Kentucky - Assisted in the development of three-dimensional groundwater flow and transport models for the regional hydrologic system underlying the plant to evaluate the nature and extent of contamination, flow and transport of contamination, and analyze the feasibility of remedial alternatives. MODMAN, an HSI GeoTrans-developed optimization module for MODFLOW, was used to evaluate the efficiency of the five plume containment alternatives.

E.I. duPont de Nemours & Company, Savannah River Site, Aiken, South Carolina - Assisted in technical support and development of a three-dimensional finite-difference flow model for Savannah River Plant. The model was used as a tool to assist the facility in groundwater resources management and to predict the response of the flow system to various plant activities. The numerical code FTWORK was applied over a 500-square-mile area with emphasis on the Tuscaloosa (Middendorf) Aquifer. Evaluation was made for a proposed corrective action.

Feed Materials Production Center, Fernald, Ohio - Provided consultation to the State of Ohio in the oversight, evaluation, and review of the RI/FS performed for the FMPC site by DOE and its contractors. Six operable units were identified at the site including waste storage areas, solid waste areas, facilities/suspect areas, K-65 silos, environmental media, and south groundwater plume.

Plessey, through Latham & Watkins, Park Ridge, New Jersey - Provided litigation support. Produced an expert report and was deposed regarding client's contribution to groundwater contamination of drinking water wells in the borough. Evaluated the reasonableness of Park Ridge's past and future remediation costs.

Nationally Recognized Authority - Authority on geohydrologic transport analysis, including groundwater flow, heat and solute transport in porous media for a wide range of applications. Authored over 90 publications on general groundwater subjects, vadose zone evaluation, computer modeling, geochemistry, and groundwater contamination and hazardous waste disposal. Frequently provides expert witness testimony, litigation support and regulatory compliance services for clients throughout the United States.

Department of Defense - Member of an expert panel advising the Air Force on Non-Aqueous Phase Liquid issues, and a co-author of a document entitled *A Review of Groundwater Modeling Needs for the U.S. Army*. This work has involved briefings with the Corps of Engineers in Vicksburg. Member of the Technology Selection Board of DOD's Advanced Applied Technology Demonstration Facility (AATDF) at Rice University.

Principal Author - *Subsurface Remediation Modeling–A State-of-the-Art Review,* which analyzes the effectiveness of models to assess such remedial actions as: bioremediation, chemical oxidation/reaction, chemical fixation, *in situ* vitrification, pump-and-treat, free phase NAPL recovery, soil vapor extraction, air sparging, soil flushing, thermal desorption, electro-osmosis, and low permeability barriers.

Expert Testimony and Technical Support, Fresno, California - Project Manager for evaluation of pesticide impacts to groundwater supply wells. Managed the development of a geographic information system (GIS) database containing over 10,000 well records and covering approximately 250 square miles. Data included: base map information, historical water-level maps, historical DBCP and EDB (pesticides) concentrations measured in groundwater, aquifer parameter values, geologic data, crop patterns, and documented applications of DBCP and EDB. Also provided deposition testimony as an expert witness. Case involved graphical analysis and calculations to determine sources of pesticides in dozens of municipal wells.

Union-Bleachery RI/FS--Served as principal investigator of RI/FS conducted in South Carolina as part of a private party cost recovery under CERCLA. The site had nine operable units where chromium was the primary contaminant.

Monsanto, Pensacola, Florida - Project Manager for successful support of deep-well injection permit at Florida Plant.

PSL RI/FS, South Carolina - Principal Investigator of RI/FS as part of a private party cost recovery at a Superfund site. The site had 15 operable units where the constituents of concern were metals and VOCs.

Professional Certification:

Certified Professional Geologist, #309, DE
Certified Professional Geologist, #341, IN
Certified Professional Geologist, #273, VA
Certified Professional Geologist, #562, SC
Certified Professional Geologist, #275, FL
American Institute of Professional Geologists (AIPG), #6020
American Institute of Hydrology-Professional Hydrogeologist, #886

Awards:

Phi Beta Kappa
Pi Mu Epsilon
Sigma Xi
Summa Cum Laude
Chevron Senior Scholarship
NDEA Title IV Fellowship
Who's Who in Frontier Science and Technology

ASCE 1985 Wesley W. Horner Award
NWWA 1987 Distinguished Seminar Series
26th Henry W. Shaw Lecture in Civil Engineering (North Carolina State University)
1994 AIH C.V. Theis Award

Teaching Experience:

Participated in short course on Chemical Risk Management - A Practical Approach for Implementing Risk-Based Decisions for Corrective Action, Sante Fe, NM, April 27 - May 1, 1998.

Presentation to The Potomac Geophysical Society on Intrinsic Remediation, May 16, 1996.

Presentation to Environmental Hydrology Colloquium at The University of Cincinnati on Intrinsic Bioremediation, February 23, 1996.

Participated in American Petroleum Institute's Workshop on Comparative Evaluation of Groundwater Biodegradation Models, Fort Worth, Texas, May 8-9, 1995.

Participated in Electric Power Research Institute's (Manufactured Gas Plant) Advisory Committee Meeting on DNAPL Characterization, Removal and Recycling, New Orleans, Louisiana, March 29-30, 1995.

Participated in short course on Chemical Risk Assessment for Environmental Compliance and Dose Reconstruction, Kiawah Is, SC, Feb. 27-Mar 3, 1995.

Participated in Stevens Institute of Technology's Seminar on Remediation of NAPL Contaminated Sites, Hoboken, New Jersey (March 14-15, 1994) and Boston, Massachusetts (April 5-6, 1994).

Participated in U.S. Environmental Protection Agency Seminar on Characterizing and Remediating Dense Nonaqueous Phase Liquids at Hazardous Sites, taught at all 10 Environmental Protection Agency regional offices, Spring - Summer, 1993.

Taught short course on "Practical Contaminant Modeling" as part of the 1993 Spring meeting of the American Institute of Hydrology on May 16, 1993 in Washington, D.C.

Participated in workshop to "Identify Barriers to *In Situ* Ground-Water Remediation" sponsored by the U.S. Environmental Protection Agency; served as group spokesperson (June 24-25, 1992).

Participated in Subsurface Restoration Conference sponsored by the U.S. EPA, presenting a talk entitled "Site Characterization: Use of Site Characterization Data to Select Applicable Remediation Technologies" (June 21-24, 1992).

Participated in workshop entitled "Introduction to Ground Water Modeling" at the National Water Well Association meeting in Washington, D.C. (October 21-23, 1991).

Participated in workshop entitled "Dense Nonaqueous Phase Liquids," sponsored by the U.S. EPA, presented a talk on "Monitoring and Modeling DNAPLs (April 16-18, 1991).

Participated in symposium on Radioactive Waste Repository Licensing, sponsored by the Broad on Radioactive Waste Management of the National Research Council, September 1990.

Taught "Modeling of GroundWater Flow" as part of the 1990 Spring meeting of the American Institute of Hydrology on March 14, 1990 in Las Vegas, Nevada.

Participated in U.S. EPA Seminar on Site Characterization for Subsurface Remediation, taught at all 10 EPA regional offices, Fall 1989 - Spring 1990.

Participated in RSKERL Ada Technical Assistance Program: Oily WasteFate, Transport, Site Characterization, Remediation, Denver, Colorado, May 17-18, 1989.

Taught short course (3-1/2 days) on "Hydrogeology and Groundwater Pollution" at the U.S. Department of Energy, Grand Junction, Colorado compound, November 28 - December 2, 1988.

Participated in short course on "Risk Assessment and Management for Hazardous Materials: From Cradle to Grave" at The Center for Risk Management of Engineering Systems of the University of Virginia, October 25-26, 1988.

Taught seminar in advanced hydrology (including well testing and modeling) at the George Washington University, Spring Semester 1979; Spring Semester 1983; Spring Semester 1985; Spring Semester 1987; as an Associate Professorial Lecturer in Geology.

Participated in the U.S. Geological Survey training courses in groundwater modeling, advanced groundwater hydrology, and salt waterfresh water relationships.

Participated in a short course held at the University of Southern California on recent advances in reservoir simulation, July 5-9, 1977.

Taught groundwater modeling short courses at the Holcomb Research Institute, Butler University, Indianapolis, Indiana, April and June 1980; May and June 1981; August 1982 (with Dr. Jacob Bear); March 1983; March 1984; March 1985; March 1986; March 1987; March 1988; March 1989, April 1989.

Included in the U.S. Geological Survey Centennial (1979) lecture series made available to Sigma Xi chapters.

Taught introduction to groundwater modeling short course at EPA Headquarters, Washington, D.C., March 1980, and EPA Region IV, Atlanta, Georgia, November 1981; taught groundwater modeling short course using personal computers at EPA Region IV, Atlanta, Georgia, February 1985. Taught a groundwater modeling short course at Georgia Southwestern College, Americus, Georgia, July 1982.

Taught a groundwater modeling short courses to St. Johns River Water Management District, Palatka, Florida, October 1982 and October 1983; and to South Florida Water Management District, October 1983 and February 1986; and to Southwest Florida Water Management District, October 1984 and July 1986.

Included in the University of South Florida's seminar on pesticides in groundwater, May 1984.

Committees:

Member, Board on Army Science and Technology's Committee on Review and Evaluation of the Army Non-Stockpile Chemical Materiel Disposal Program, 1998-2000.

Member, Peer Review of SERDP Project on Cleanup Modeling and Simulation, Vicksburg, MS, June 7-9, 1998.

Consultant, U.S. Environmental Protection Agency's SES Recruitment Committee, 1998.

Member, Technical Advisory Group (TAG) to support the Interagency DNAPL Consortium, 1998.

Session Chair, International Containment Technology Conference, St. Petersburg, Florida, February 9-12, 1997.

Member of the site visit committee of the Natural Sciences and Engineering Council of Canada. Site visit was to the University of Waterloo to review proposal on "Field Behavior of Dense Solvents in Groundwater," July 27, 1988. Continued on committee until 1991.

Member of Water Science and Technology Board Committee on Ground Water Modeling Assessment, 1987-1989.

Member of the Water Pollution Control Federation's Groundwater Committee, 1987-1989.

Member of the Laboratory Director's Annual Review Committee, Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, 1987.

National Research Council's Water Science and Technology Board, 1986 - 1989.

Secretary of the Hydrology Section of the American Geophysical Union, 1986 - 1988.

Member of U.S. Environmental Protection Agency Panel on Leak Detection for Underground Storage Tanks, 1987.

Co-convener of the American Geophysical Union Chapman Conference on Microbial Process in the Transport, Fate and In-situ Treatment of Subsurface Contaminants, Snowbird, Utah, October 1986.

Member of the U.S. Department of Energy Radionuclide Migration (RNM) Project Peer Review Committee, 1986.

Member of the U.S. Environmental Protection Agency Ground-Water Modeling Study Group, February 1986 - May 1986.

Co-convener of the American Geophysical Union Symposium on Saturated/Unsaturated Ground-Water Flow Systems: Measurement and Estimation of Parameters. Baltimore, Maryland, May 1985.

Member of the Ground-Water Research Subcommittee of the Science Advisory Board of the U.S. Environmental Protection Agency, December 1984 - June 1985.

Co-convener of the American Geophysical Union Symposium on Miscible and Immiscible Transport in Ground Water, Cincinnati, Ohio, May 1984.

National Research Council Panel on Groundwater Contamination (1983).

Advisory panel for the Office of Technology Assessment (Congress of the United States) on national groundwater contamination (1983).

International technical advisory committee of the International Ground Water Modeling Center (1983 - 1985).

Co-convener of the American Geophysical Union Symposium on the Role of the Unsaturated Zone in Radioactive and Hazardous Waste Disposal, Philadelphia, Pennsylvania, May 1982.

Co-convener of the Gordon Conference on Fluids in Permeable Media: Mathematics of Modeling and Simulating, Andover, New Hampshire, July 1980.

Co-convener of the American Geophysical Union Symposium on the Unsaturated Zone as a Barrier in Waste Disposal, Washington, D.C., May 1979.

Co-convener of the Geological Society of America Penrose Conference on Heat Transport Processes in the Earth, Vail, Colorado, November 1978.

Member of the Editorial Board for Journal of Contaminant Hydrology (1985 - 1992).

Member of the Editorial Board for Ground Water (1980 - 1984; 1992 - 1995).

Member of the Editorial Board for Geology (1979 - 1982).

Member of the 1982 - 1985 American Geophysical Union Ground Water Committee.

Member of the 1978 - 1983 American Geophysical Union Committee on Water in the Unsaturated Zone.

Member of the 1977 - 1978 ERDA Geothermal Exploration, Modeling and Reservoir Assessment Committee.

Professional Affiliations:

Society of Petroleum Engineers, Member
American Geophysical Union, Member
Geological Society of America, Fellow
National Ground Water Association, Member
American Society of Civil Engineers, Member
International Association of Hydrogeologists, Member
American Institute of Hydrology

Publications:

Publications in Water Supply :

Andersen, P.F., R.M. Cohen, and J.W. Mercer, 1984. Numerical modeling as a conceptual tool to assess drawdown in a multiaquifer system, symposium on Practical Applications of Ground Water Models, sponsored by National Water Well Association, Columbus, Ohio.

Publications in Vadose Zone Evaluation :

Huyakorn, P.S., J.W. Mercer, and D.S. Ward, 1985. Finite-element matrix and mass balance computational schemes for transport in variably-saturated porous media, *Water Resources Research*, 21(3):346-358.

Mercer, J.W., P.S.C. Rao, and I.W. Marine, (Eds.), 1983. *Role of the Unsaturated Zone in Radioactive and Hazardous Waste Disposal:* Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 339 pp.

Mercer, J.W., and C.R. Faust, 1976. The application of finite-element techniques to immiscible flow in porous media, presented at the International Conference on Finite Elements in Water Resources, Princeton University.

Publications in Wetland Hydrology:

Hollis, T., P. Heurteaux, and J.W. Mercer, 1989. The implication of groundwater extractions for the long-term future of the Donana National Park, report of the WWF/IUCN/ADENA Mission to the Donana National Park, May, 60 pp.

Publications in General Groundwater :

Moore, J.E., A. Zaporozec, and J.W. Mercer, 1995. *Groundwater, A Primer*, American Geological Institute, Alexandria, VA, 53pp.

Mercer, J.W., R.R. Rabold, and W.R. Waldrop, 1991. Practical technology resulting from MADE research, *Proceedings of the International Symposium on Ground Water*, American Society of Civil Engineering (July 29-August 2), Nashville, TN, pp. 113-119.

Faust, C.R., and J.W. Mercer, 1984. Evaluation of the skin effect in slug tests, *Water Resources Research*, 20(2):504506.

Publications in General Modeling :

Mercer, J.W., 1991. Common mistakes in model applications, *Proceedings of the International Symposium on Ground Water*, American Society of Civil Engineering (July 29 - August 2), Nashville, TN, pp. 1-6.

Mercer, J.W., 1988. Standards of performance for investigative methods used in assessing groundwater pollution problems with emphases on the use and abuse on numerical models, *Proceedings of the Workshop on Groundwater Quality Protection*, Water Pollution Control Federation Annual Conference Workshop, Dallas, Texas.

Konikow, L.F., and J.W. Mercer, 1988. Groundwater flow and transport modeling, *Journal of Hydrology*, 100:379-409.

van der Heijde, P.K.M., P.S. Huyakorn, and J.W. Mercer, 1985. Testing and validation of groundwater models, Symposium on Practical Applications of Ground Water Models, pp. 14-31.

Mercer, J.W., and C.R. Faust, 1981. *GroundWater Modeling*, National Water Well Association, Columbus, Ohio, 60 pp.

Faust, C.R., and J.W. Mercer, 1980. Groundwater modeling: Recent developments: *Ground Water* , 18(6).

Mercer, J.W., and C.R. Faust, 1980. Groundwater modeling: Applications: *Ground Water* , 18(5).

Faust, C.R., and J.W. Mercer, 1980. Groundwater modeling: Numerical models: *Ground Water* , 18(4).

Mercer, J.W., and C.R. Faust, 1980. Groundwater modeling: Mathematical models, *Ground Water* , 18(3):212-227.

Mercer, J.W., and C.R. Faust, 1980. Groundwater modeling: An overview, *Ground Water* , 18(2):108-115.

Wells, R.B., C.R. Faust, and J.W. Mercer, 1976. A Cross-Section Plotting Program (CSPP) for Gridded (MAP) Data, U.S. Geological Survey, *Open-File Report 7668* .

Faust, C.R., and J.W. Mercer, 1976. An analysis of finite-difference and finite-element techniques for geothermal reservoir simulation, *Proceedings of Fourth Society of Petroleum Engineers Symposium on Numerical Simulation of Reservoir Performance*, Los Angeles, California, February 19-20.

Publications in Geochemistry :

Li, T.M.C., J.W. Mercer, C.R. Faust, and R.J. Greenfield, 1978. Simulation of geothermal reservoirs including changes in porosity and permeability due to silica-water reactions, presented at the Fourth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California.

Publications in Optimization Techniques :

Maddock, T., III, J.W. Mercer, and C.R. Faust, 1982. Management model for power production from a geothermal field: 1. Hot water reservoir and power plant model, *Water Resources Research*, 18(3):499-512.

Maddock, T. III, J.W. Mercer, C.R. Faust, and E.D. Attanasi, 1979. Management model for electrical power production from a hotwater geothermal reservoir, Reports on Natural Resources Systems, No. 34, University of Arizona, Tucson, Arizona, 114 pp.

Publications in Sea Water Intrusion :

Andersen, P.F., H.O. White, Jr., and J.W. Mercer, 1988. Numerical modeling of saltwater intrusion at Hallandale, Florida, *Ground Wate* , 26(5):619-630.

Huyakorn, P.S., P.F. Andersen, J.W. Mercer, and H.O. White, Jr., 1987. Saltwater intrusion in aquifers: Development and testing of a three-dimensional, finite-element model, *Water Resources Research*, 23(2):293-312.

Andersen, P.F., H.O. White, J.W. Mercer, A.D. Truschel and P.S. Huyakorn, 1986. Numerical modeling of ground water flow and saltwater transport in Northern Pinellas County, Florida, *Proceedings of FOCUS Conference on Southeastern Ground Water Issues*, National Water Well Association, Dublin, Ohio, pp. 4194-49.

Mercer, J.W., B.H. Lester, S.D. Thomas, and R.L. Bartel, 1986. Simulation of saltwater intrusion in Volusia County, Florida, *Water Resources Bulletin*, 22(6):951-965.

Huyakorn, P.S., J.W. Mercer, and P.F. Andersen, 1986. Seawater intrusion in coastal aquifers: Theory, finite-element solution, and verification tests, VI International Conference on Finite-Elements in Water Resources, Lisbon, Portugal.

Faust, C.R., and J.W. Mercer, 1982. Preliminary analysis of groundwater development and brackish water upconing at Virginia Beach, Virginia, Special Publications: Number 1, Georgia Southwestern College *Studies of the Hydrogeology of the Southeastern United States:* 1981, B.F. Beck (ed.), pp. 30-37, pp. 797-818.

Mercer, J.W., S.P. Larson, and C.R. Faust, 1980. Simulation of saltwater interface motion, *Ground Water*, 18(4):374-385.

Mercer, J.W., S.P. Larson, and C.R. Faust, 1980. Finite-difference model to simulate the areal flow of salt water and fresh water separated by an interface, U.S. Geological Survey, *OpenFile Report 80-407*, 88 pp.

Publications in Groundwater Contamination and Hazardous Waste Disposal:

Mercer, J.W., Z. Adeel, and C.R. Faust, 1997. A Review of NAPL Modeling Approaches for Remediation, presented at the International Conference on Groundwater Quality Protection, Remedial Technology and Management Policy for NAPL Contamination, Taipei, Taiwan (December).

Mercer, J.W., R.M. Parker, and C.P. Spalding, 1997. Chapter 9, Use of Site Characterization Data to Select Applicable Remediation Technologies, in *Subsurface Restoration* (C.H. Ward, J.A. Cherry, and M.R. Scalf, eds.), Ann Arbor Press, Inc., Chelsea, MI.

Mercer, J.W., Z. Adeel, and C.R. Faust, 1996. A review of NAPL modeling approaches for remediation, Non-Aqueous Phase Liquids (NAPLs) in Subsurface Environments: *Assessment and Remediation, Proceedings*, ASCE National Convection, Washington, D.C., Nov. 12-14, 1996, pp. 46-65.

Rabideau, A.J. (With contributions from J.W. Mercer, et al.), 1996. Section 10 Contaminant transport modeling, in *Assessment of Barrier Containment Technologies*, R.R. Rumer and J.K. Mitchell (Eds), U.S. Department of Energy, U.S. Environmental Protection Agency, and DuPont Co., pp. 247-299.

Lester, B.H. and J.W. Mercer, 1995. Comparative Evaluation of Groundwater Biodegradation Models: Summary of the API Workshop NGWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Ground Water - Prevention, Detection and Restoration, November 29 - December 1, Houston, TX.

Srinivasan, P., S. Donahoe, and J.W. Mercer, 1995. Use of Geographic Information Systems (GIS) in Risk-Based Screening, *The Professional Geologist*, October, 11-12 pp.

Cohen, R.M., J.W. Mercer, and R.M. Greenwald, 1995. Design guidelines for conventional pump-and-treat systems, U.S. Environmental Protection Agency Ground Water Issue, Ada, OK.

Jordan, D.L., J.W. Mercer, and R.M. Cohen, 1995. Review of mathematical modeling for evaluating soil vapor extraction systems, U.S. Environmental Protection Agency Report EPA/540/R-95/513, Cincinnati, OH.

Jordan, D.L., J.W. Mercer, and R.M. Cohen, 1995. Review of mathematical modeling for evaluation of SVE applications, presented at EPA's 21st Annual RREL Research Symposium, April 4-6, Cincinnati, OH.

Cohen, R.M., A.H. Vincent, J.W. Mercer, C.R. Faust, and C.P. Spalding, 1994. Methods for monitoring pump-and-treat performance, U.S. Environmental Protection Agency publication EPA/600/R-94/123, Ada, Oklahoma.

Mercer, J.W. and R.M. Cohen, 1994. The limitations of pump-and-treat systems in groundwater remediation, *Pollution Prevention in South Carolina*, 11(1): 18-21.

Cohen, R.M., J.W. Mercer, and I. Star, 1993. Delineating subsurface DNAPL using direct and indirect methods, Air & Waste Management Association Annual Meeting, Denver, Colorado, June 14-19, 1993.

Cohen, R.M., and J.W. Mercer, 1993. *DNAPL Site Evaluation*, C.K. Smoley, Boca Raton, Florida.

Mercer, J.W. and R.K. Waddell, 1993. Contaminant transport in groundwater (Chapter 16) in *Handbook of Hydrology*, D.R. Maidment (Ed.), McGraw-Hill, New York.

U.S. Environmental Protection Agency, 1992. Dense Nonaqueous Phase Liquids -- A Workshop Summary, Dallas, Texas, April 16-18, 1992, EPA/600/R-92/030 (Contributing author).

Mercer, J.W. and R.M. Cohen, 1992. Site characterization for DNAPL control/restoration, *Proceedings of the Water Environment Federation Pre-Conference Seminar on Detection and Restoration of DNAPLs in Groundwater at Hazardous Waste Sites*, New Orleans, LA, September 20.

Ward, D.S., J.W. Mercer, and L.L. August, 1992. Analysis of groundwater flow and injection fluid transport in the Floridan Aquifer near Pensacola, Florida, *Ground Water*, 30(3): 403-414.

Mercer, J.W., and C.P. Spalding, 1991. Chapter 2 Site Characterization Overview; Chapter 3 Geologic Aspects of Site Remediation; Chapter 4 Characterization of Water Movement in the Saturated Zone; Chapter 5 Characterization of the Vadose Zone; and Chapter 6 Characterization of Water Movement in Saturated Fractured

Media, in Site Characterization for Subsurface Remediation, U.S. EPA Seminar Publication EPA/625/4-91/026, Cincinnati, Ohio, 259 pp.

Mercer, J.W., and D.C. Skipp, 1990. Considerations in the design of pump-and-treat remediation systems, *Superfund '90: Proceedings of the 11th National Conference*, HMCRI, 720-725.

Mercer, J.W., and R.M. Cohen, 1990. A review of immiscible fluids in the subsurface: Properties, models, characterization and remediation, *Journal of Contaminant Hydrology*, 6(2):107-163.

Mercer, J.W., D.C. Skipp, and D. Giffin, 1990. Basics of pump-and-treat groundwater remediation, U.S. Environmental Protection Agency EPA/600/890/003, Ada, Oklahoma, 31 pp.

Mercer, J.W., 1990. Don't gamble on a real estate purchase: An environmental assessment can separate winners from losers, American Society of Appraisers, *Valuation*, 35(1):116-121.

Faust, C.R., J.H. Guswa, and J.W. Mercer, 1989. Simulation of threedimensional flow of immiscible fluids within and below the unsaturated zone, *Water Resources Research*, 25(12):2449-2464.

Mercer, J.W., D.A. Giffin, Jr., J.C. Herweijer, and P. Srinivasan, 1989. Groundwater contamination: Processes, characterization, analysis, and remediation, International Workshop on Appropriate Methodologies or Development and Management of Groundwater Resources in Developing Countries, Hyderabad, India, Feb 28 - Mar 4, 1989.

Bouwer, E., J. Mercer, M. Kavanaugh, and F. DiGiano, 1988. Coping with groundwater contamination, *Journal Water Pollution Control Federation*, 6(8):1414-1428.

Srinivasan, P., and J.W. Mercer, 1988. Simulation of biodegradation and sorption processes in groundwater, *Ground Water*, 26(4):475-487.

Faust, C.R., R.R. Rabold, and J.W. Mercer, 1988. Modeling remedial actions at SArea, Niagara Falls, NY, *Proceedings of the Seminar on Impact of Hazardous Waste Facilities on Water Utilities*, American Water Works Association Annual Conference, Orlando, Florida.

Mercer, J.W., C.R. Faust, A.D. Truschel, and R.M. Cohen, 1987. Control of Groundwater Contamination: Case Studies, *Proceedings of Detection, Control, and Renovation of Contaminated Ground Water*, American Society of Civil Engineers, Environmental Engineering Division, pp. 121-133.

Duffield, G.M., D.R. Buss, D.E. Stephenson, and J.W. Mercer, 1987. A grid refinement approach to flow and transport modeling of a proposed groundwater corrective action at the Savannah River Plant, Aiken, South Carolina, *Proceedings of the Conference on Solving Ground Water Problems with Models*, National Water Well Association, Dublin, Ohio, pp. 1087-1120.

Ward, D.S., D.R. Buss, J.W. Mercer, and S.S. Hughes, 1987. Evaluation of a groundwater corrective action of the ChemDyne Hazardous Waste site using a telescopic mesh refinement modeling approach, *Water Resources Research*, 23(4):603-617.

Ward, D.S., T.D. Wadsworth, D.R. Buss, and J.W. Mercer, 1986. Analysis of potential failure mechanisms pertaining to hazardous waste injection in the Texas Gulf Coast Region, *Journal of the Underground Injection Practices Council*, 1:120-152.

Buss, D.R., B.H. Lester, and J.W. Mercer, 1986. A numerical simulation study of deepwell injection, *Current Practices in Environmental Science and Engineering*, 2:93-117.

Mercer, J.W., C.R. Faust, R.M. Cohen, P.F. Andersen, and P.S. Huyakorn, 1985. Remedial action assessment for hazardous waste sites via numerical simulation, *Water Management and Research*, 3:377-387.

Mercer, J.W., C.R. Faust, R.M. Cohen, P.F. Andersen, and P.S. Huyakorn, 1984. Remedial Action Assessment for Hazardous Waste Sites Via Numerical Simulation, Seventh Annual Madison Waste Conference on Municipal & Industrial Waste, University of Wisconsin, Madison, Wisconsin.

Mercer, J.W., C.R. Faust, and L.R. Silka, 1984. Groundwater flow modeling study of the Love Canal area, New York, *Groundwater Contamination* , Bredehoeft, J.D. and T.M. Uesselman (Editors), National Research Council, Studies in Geophysics, pp. 109-119.

Cohen, R.M. and J.W. Mercer, 1984. Evaluation of a proposed synthetic cap and concrete cutoff wall at Love Canal using a crosssectional model, Fourth National Symposium and Exposition on Aquifer Restoration and GroundWater Monitoring, Columbus, Ohio.

Andersen, P.F., C.R. Faust, and J.W. Mercer, 1984. Analysis of conceptual designs for remedial measures at Lipari landfill, New Jersey, *Ground Water*, 22(2):176-190.

Mercer, J.W., L.R. Silka, and C.R. Faust, 1983. Modeling groundwater flow at Love Canal, New York, *ASCE Journal of Environmental Engineering*, 109(4):924-942.

Silka, L.R. and J.W. Mercer, l983. Evaluation of remedial actions for groundwater contamination, presented at the 3rd National Conference and Exhibition on Management of Uncontrolled Hazardous Waste Sites, Washington, D.C.

Mercer, J.W., L.R. Silka, C.R. Faust, and A.G. Kretschek, l98l. Draft final report on EPA test problems for groundwater model evaluation, GeoTrans Report No. 07200K0l, 92 pp.

Faust, C.R., L.R. Silka, and J.W. Mercer, l98l. Computer modeling and groundwater protection, Guest Editorial in *Ground Water*, l9(4):362-365.

Publications in Geothermal Resource Analysis:

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Appendix I (Revised) Alternatives for Lessening Groundwater Quality Impacts

Two methods have been evaluated for reducing the significant impacts of recharging groundwater with Colorado River water: direct delivery of State Water Project (SWP) water and desalination of Colorado River water.

I.1 ALTERNATIVE 4 — DIRECT SWP DELIVERY

The direct importation of SWP water to the Coachella Valley could reduce the significant adverse impact of increased salt loading of imported Colorado River water on Coachella Valley groundwater basins. The closest point of connection to the SWP is the Devil Canyon Afterbay in San Bernardino. However, another possible delivery point is the California Aqueduct near the Mojave River. In addition, the potential use of Metropolitan's Colorado River Aqueduct has been identified by commenters to the Draft PEIR.

I.1.1 Background

DWR completed a study in 1979 (DWR, 1979a) of various alternatives for delivering SWP water to CVWD, DWA, San Gorgonio Pass Water Agency (SGPWA), Mojave Water Agency (MWA) and San Bernardino Valley Municipal Water District (SBVMWD). The alternatives were developed to deliver the CVWD and DWA current contract entitlements of 61,200 acre-ft/yr. DWR evaluated four basic alternatives that included ten subalternatives. Six of these subalternatives were subjected to detailed evaluation. Two basic routes were evaluated: the Desert Route and the Pass Route. The Desert Route conveyed water by pipeline from the East Branch of the California Aqueduct upstream of Silverwood Lake through the Lucerne and Yucca Valleys to the Upper Coachella Valley near the confluence of the Whitewater and San Gorgonio Rivers. The Desert Route generally served MWA, CVWD and DWA with one alternative that served SBVMWD and SGPWA. The Pass Route conveyed water by pipeline from the Devil Canyon Afterbay in San Bernardino through San Gorgonio Pass to the Upper Coachella Valley. This route did not serve MWA. The estimated capital costs of the facilities ranged from $78 million to $151 million in 1976 dollars. The cost of these alternatives in 2000 dollars would range from $189 million to $365 million.

Since that time, MWA built the Mojave Pipeline to bring SWP water to the Joshua Tree–Yucca Valley area. DWR is constructing the East Branch Extension to deliver SWP water to SGPWA in the Banning–Beaumont area. Neither of these pipelines includes capacity for CVWD and DWA.

I.1.2 Capacity Options

Several capacity options are evaluated for delivering SWP water to CVWD and DWA, as shown in **Table I-1**. One option would deliver only the incremental (in excess of the baseline) SWP entitlement water that would be recharged at the Whitewater Spreading Facility. Since the average incremental recharge delivery would be 53,000 acre-ft/yr, the incremental SWP entitlement (based on 80 percent reliability) is 66,300 acre-ft/yr. This option would deliver 66,300 acre-ft/yr and have a design capacity of 120 cfs (based on the SWP contract peaking factor of 132 percent). A second option would deliver the average incremental SWP supply required for both recharge at Whitewater (53,000 acre-ft/yr) and golf course delivery in the Palm Desert area (37,000 acre-ft/yr). This option allows delivery of lower TDS water to all proposed imported uses in the Upper Valley. The proposed incremental entitlement would be 112,500 acre-ft/yr and have a design capacity of ~~210~~ 205 cfs. In both of these options, the existing average entitlement deliveries of 50,000 acre-ft/yr would continue to be delivered through the exchange agreement with Metropolitan. A third option would deliver the total current and proposed future SWP entitlement of 175,000 acre-ft/yr and have a design capacity of 320 cfs.

Table I-1
Basis for SWP Conveyance Capacity

	Units	Option 1	Option 2	Option 3	Option 4
Average Annual Flow					
Recharge	acre-ft/yr	53,000	53,000	103,000	103,000
Direct Delivery	acre-ft/yr	—	37,000	37,000	—
Total Annual	acre-ft/yr	53,000	90,000	140,000	103,000
Annual Reliability Factor		80%	80%	80%	58%
Peak Annual	acre-ft/yr	66,250	112,500	175,000	174,200
Peaking Factor		132%	132%	132%	132%
Design Flowrate	cfs	120	205	320	320

These three options are based on the assumption that SWP water would be available to CVWD and DWA according the SWP reliability estimates (average delivery is about 80 percent of the maximum annual). At the time the alternatives analysis was performed, the SWP Entitlement Transfer was not included in the Proposed Project. Consequently, the analysis was updated to consider the capacity required to convey SWP water under the schedule anticipated with the proposed SWP Entitlement Transfer (100,000 acre-ft/yr in any year with an average delivery of 50,000 acre-ft/yr). The analysis was also updated to include an allowance for interruptible water deliveries and future transfers capable of providing an average supply of 40,000 acre-ft/yr. If this interruptible water is obtained through firm entitlements to SWP water, the pipeline would need to convey an additional maximum annual flow of up to 50,000 acre-ft/yr. If only water for recharge were conveyed via a SWP pipeline (golf course water would be conveyed through the Coachella Canal as identified in the Proposed Project), the required annual capacity for SWP water would be 174,200 acre-ft/yr with a design flow rate of 318 cfs without a capacity allowance for interruptible water. Because this capacity is similar to that identified above, a 320 cfs capacity pipeline would be adequate for conveyance of SWP water for recharge only with the SWP Entitlement Transfer or for delivery of the entire future entitlement under the anticipated SWP delivery schedule. For comparison purposes, the 320 cfs options are considered in the cost evaluation.

I.1.3 Routing and Facilities

As discussed above, DWR (1979) evaluated two basic routes: the Desert Route and the Pass Route. The Pass Route is the most direct route for delivering water to CVWD and DWA. The original Pass Route included use of 15 miles of SBVMWD's Foothill Pipeline, which has a capacity of 280 cfs. A portion of this capacity is being used to convey SWP water to SGPWA through the East Branch Extension, while the remainder is reserved for SBVMWD use. Since it is unlikely that there is any remaining capacity available in the SBVMWD pipeline, CVWD and DWA would need to build a pipeline from the Devil Canyon Afterbay to the Coachella Valley.

The route evaluated is similar to that originally proposed by DWR; however, some of the pipeline features have been modified to meet the needs of CVWD and DWA. **Figure I-1** shows the potential alignment for the pipeline and the location of major facilities. **Figure I-2** shows a preliminary hydraulic profile for the largest capacity option; however, the hydraulic profiles for the other options would be similar. The pipeline would originate at the Devil Canyon Afterbay and traverse San Bernardino southeasterly through Highland, Redlands, and Mentone. The Mentone Pump Station would lift the water 550 ft over the Crafton Hills to Yucaipa. The Yucaipa Pump Station would lift the water another 500 ft to flow over the crest of San Gorgonio Pass. The pipeline would generally follow the alignment of Interstate 10 and would be located in a combination of public streets and dedicated right-of-way. The pipeline would pass through Calimesa, Beaumont, Banning, and Cabazon. A power plant would be located near Cabazon to recover about 900 feet of head. A second power plant would be located at the pipeline terminus near Windy Point to recover about 450-540 feet of head. In addition to these facilities, the second and third options would also require about 15 miles of 48-inch pipeline to convey SWP to the Upper Valley golf course delivery system. <u>A fourth option was considered that delivers SWP for recharge only based on the capacities shown in **Table I-1**.</u> ~~**Table I-1** summarizes the major facilities for each capacity option.~~

<u>A second alternative route is the Desert Route. This route was followed by MWA in the construction of its Morongo Basin pipeline (completed in 1995). This route was considered for comparison purposes in response to comments that it could be constructed in an established alignment and would require less pumping and generate more electricity. This route is shown in **Figure I-3**. The Desert Route would entail about 66 miles of 90-in diameter and 37 miles of 84-in diameter pipeline that traverses the Mojave Desert north of the San Bernardino Mountains, crosses the Morongo Pass and enters the Coachella Valley parallel to State Highway 62. One pumping station with a lift of about 660 ft would be required to raise the hydraulic grade sufficiently to flow over the pass. On the downgrade, three power plants would be required to reduce pressure. These power plants would be located near Yucca Valley, below the Morongo Pass and at the Whitewater turnout. The facilities are shown in **Table I-2**. **Figure I-4** presents the hydraulic profile for the Desert route alignment.</u>

I.1.4 Water Quality

Water from the East Branch of the SWP has an average TDS concentration of approximately 250 mg/L, <u>ranging from 112 mg/L to 375 mg/L, which is</u> much lower than the water currently delivered through the Exchange Program with Metropolitan (about 660 mg/L). In terms of TDS, the use of SWP water would provide a substantial water quality benefit compared to the Proposed Project. Therefore, delivery of the higher quality water of the SWP directly to the Coachella Valley would help address the Upper Valley water quality issue. Every acre-ft of SWP water delivered directly to the Upper Valley reduces the salt loading by 0.56 tons. If all SWP water were conveyed directly to the Valley, the salt load would be decreased by about 78,000 tons per year. If only the incremental recharge to the Upper Valley were conveyed from the SWP, the salt loading would be reduced by about 30,000 tons per year.

However, ~~SWP trihalomethane concentrations~~ the organic precursors for disinfection byproduct (DBP) formation, principally dissolved humic acids measured as total organic carbon (TOC), are substantially higher in SWP water than in Colorado River water~~, which cause the formation of disinfection byproducts when the water is disinfected by chlorination~~. SWP water also contains higher concentrations of bromide (an inorganic ion) compared to Colorado River water. These organic compounds and bromide can form DBPs (trihalomethanes and haloacetic acids) when the water is disinfected by chlorination.

A portion of these organic compounds may potentially be removed during percolation through the soil column. However, removal depends on the type of soils and the ability of the soils to adsorb organic compounds. Generally, adsorption occurs on fine-grained materials such as silts and clays. At the Whitewater Spreading Facility, the soils tend by be relatively coarse with little silt or clays. Therefore, the removal of the DBP precursors is expected to be small.

I.1.5 Environmental Impacts

In addition to the impacts of the Proposed Project, construction of this pipeline would have substantial adverse environmental impacts, including:

- Disturbance of up to 70 miles (300 to 400 acres) of roads and undeveloped right-of-way during construction for the San Gorgonio Route and up to 103 miles (up to 1,500 acres) for the Desert Route. Scarring of the terrain by pipeline trenching and backfill. Permanent modifications of landforms near pumping and power recovery locations. If the pipeline can be located in or parallel to the alignment of the Morongo Basin Pipeline, these impacts may be reduced.

- Changes in erosion, drainage patterns and runoff along pipeline alignment.

- Potential loss of plant and animal resources along pipeline route and at pumping/power recovery sites.

- Potential loss of cultural resources along pipeline route and at pumping/power recovery sites.

- Increased noise during construction.

- Air quality impacts from construction equipment and dust during construction; additional air quality impacts from increased energy generation for pumping.

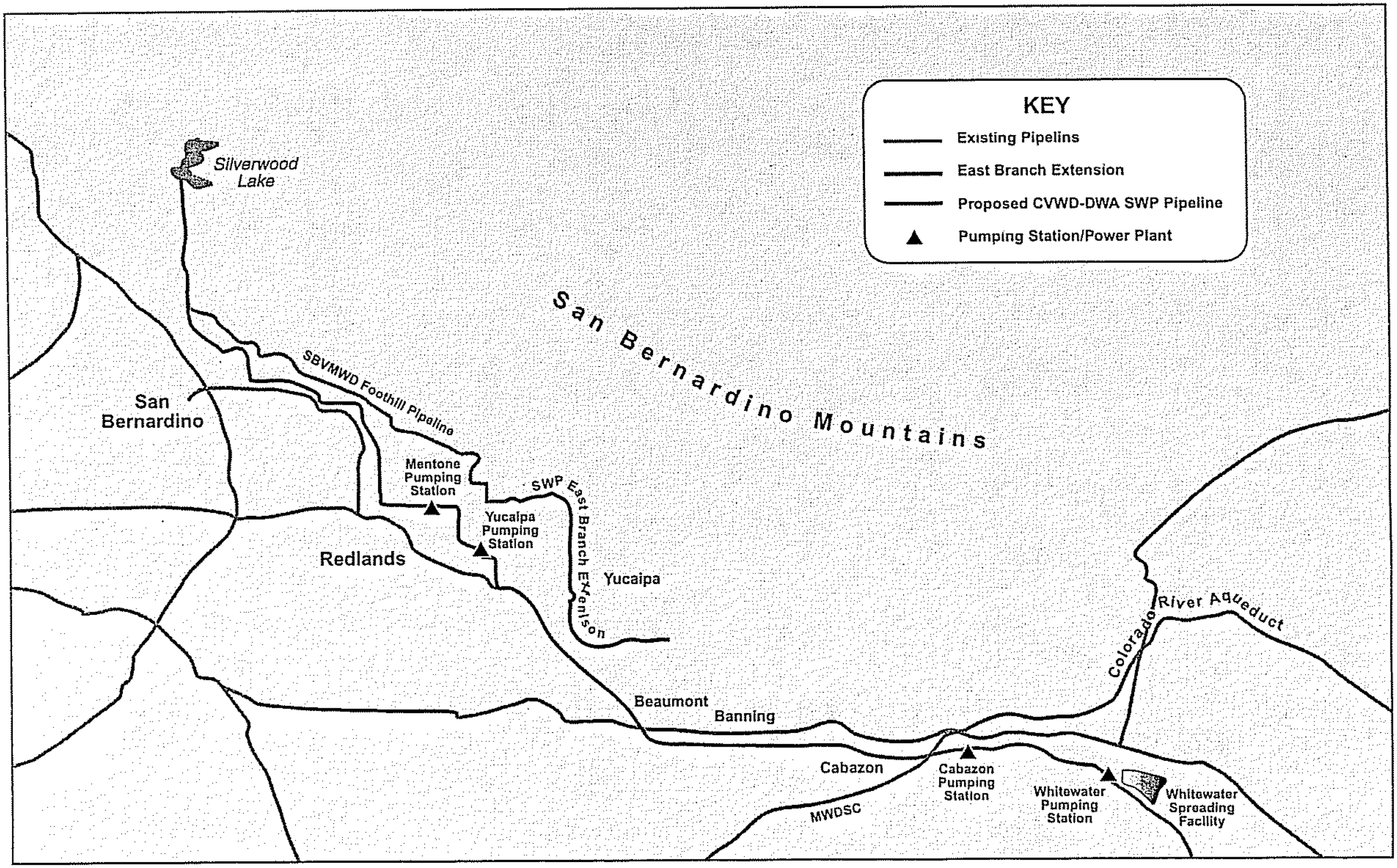

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Figure I-1

Conceptual Alignment for SWP Extension to Coachella Valley

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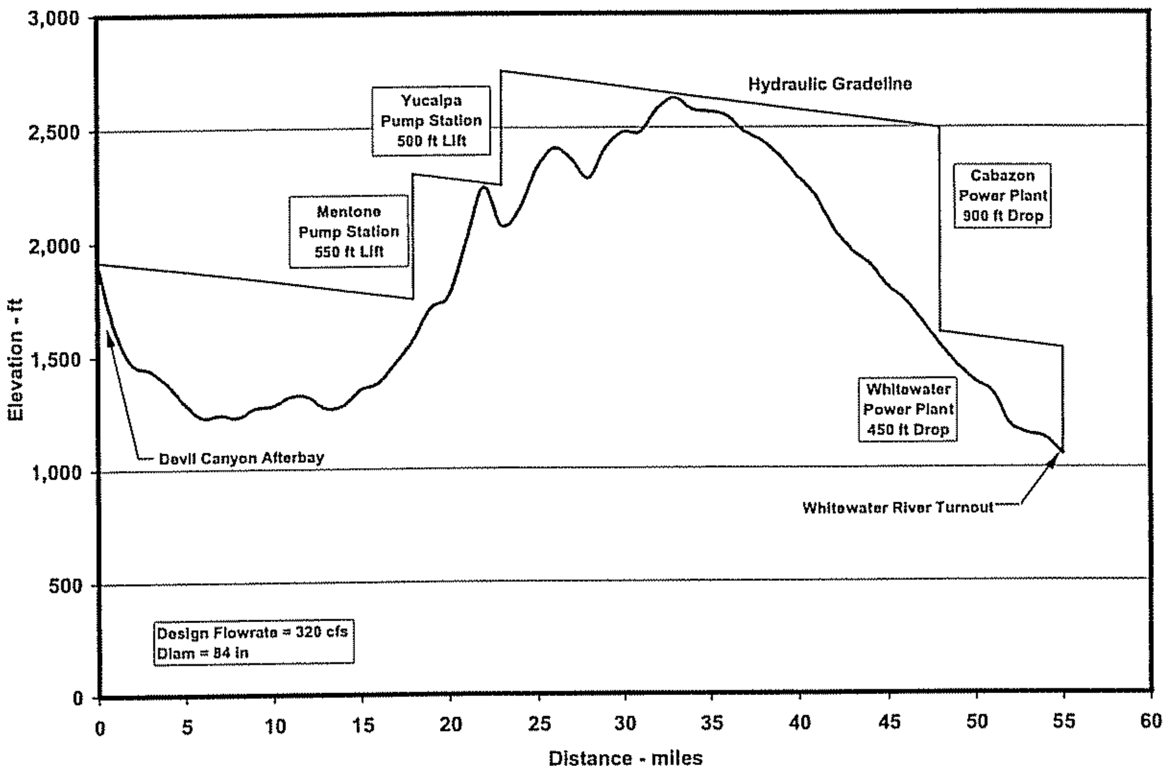
Figure I-2
Hydraulic Profile for SWP Extension to Coachella Valley



- Temporary disruption of traffic patterns and increased traffic congestion during construction activities.

- Net energy requirement of about 400 kWh/acre-ft. Approximately 2.4 to 6.4 megawatts of additional power generation capacity required. Potential impact on existing energy infrastructure for both pumping and recovered energy

- Increased salt for the coastal plain (MWDSC service area). Increased salt load would range from 30,000 to 78,000 tons of salt per year.

- Reduced salt load to the Upper Coachella Valley would reduce the average increase in groundwater TDS from 315 mg/L under the Proposed Project to 150 mg/L over 35 years if all SWP were imported through a dedicated pipeline. If only the incremental water delivered for recharge were delivered by pipeline, the projected TDS increase in groundwater would be 260 mg/L over 35 years. ~~There would be no water quality benefit for the Lower Valley~~ Because there is insufficient SWP water entitlement to meet both Upper and Lower Valley needs. Therefore, this option provides no water quality benefit to the Lower Valley.

Figure I-3
Conceptual Alignment for SWP Extension to Coachella Valley Using the Desert Route

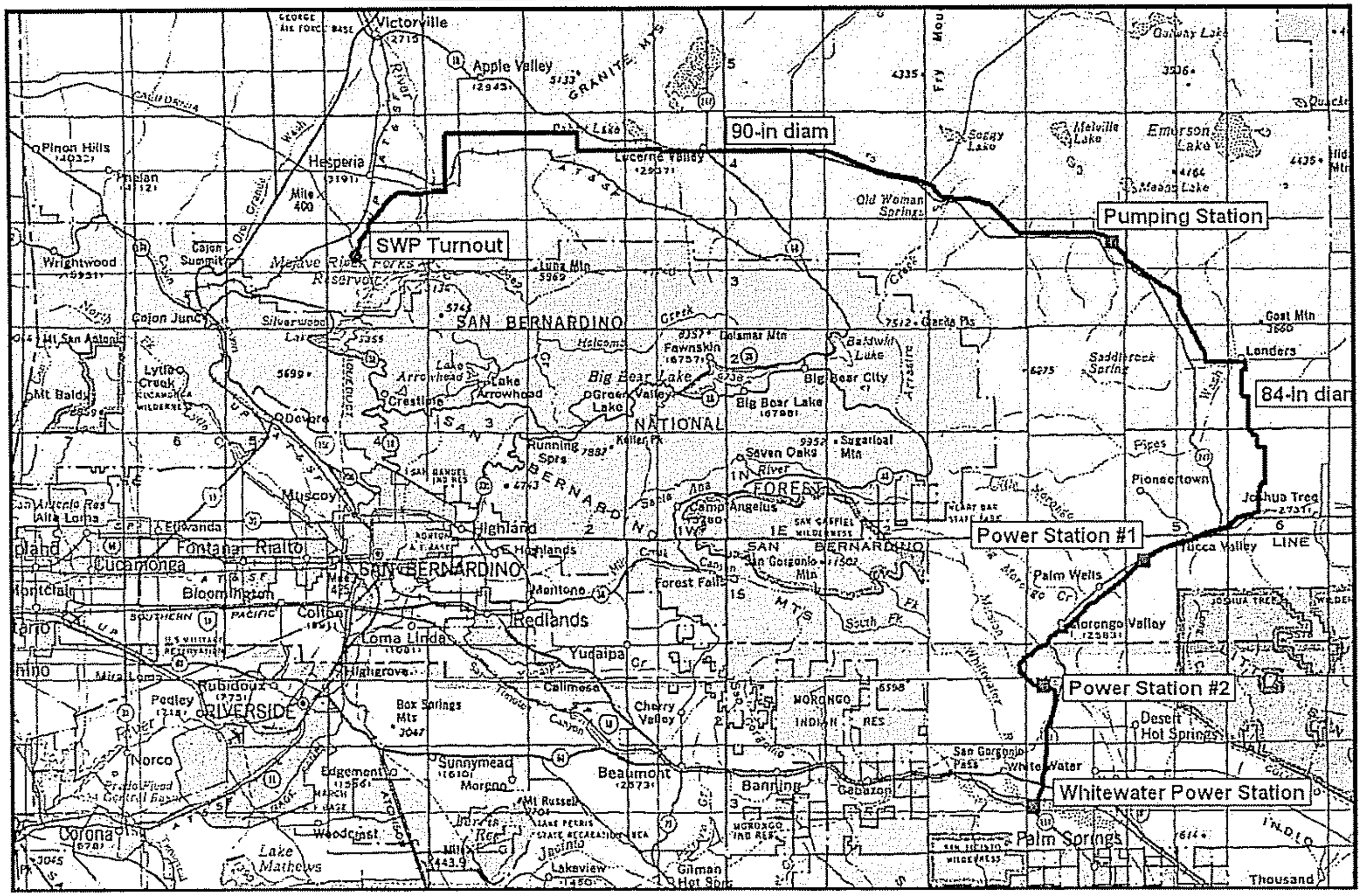
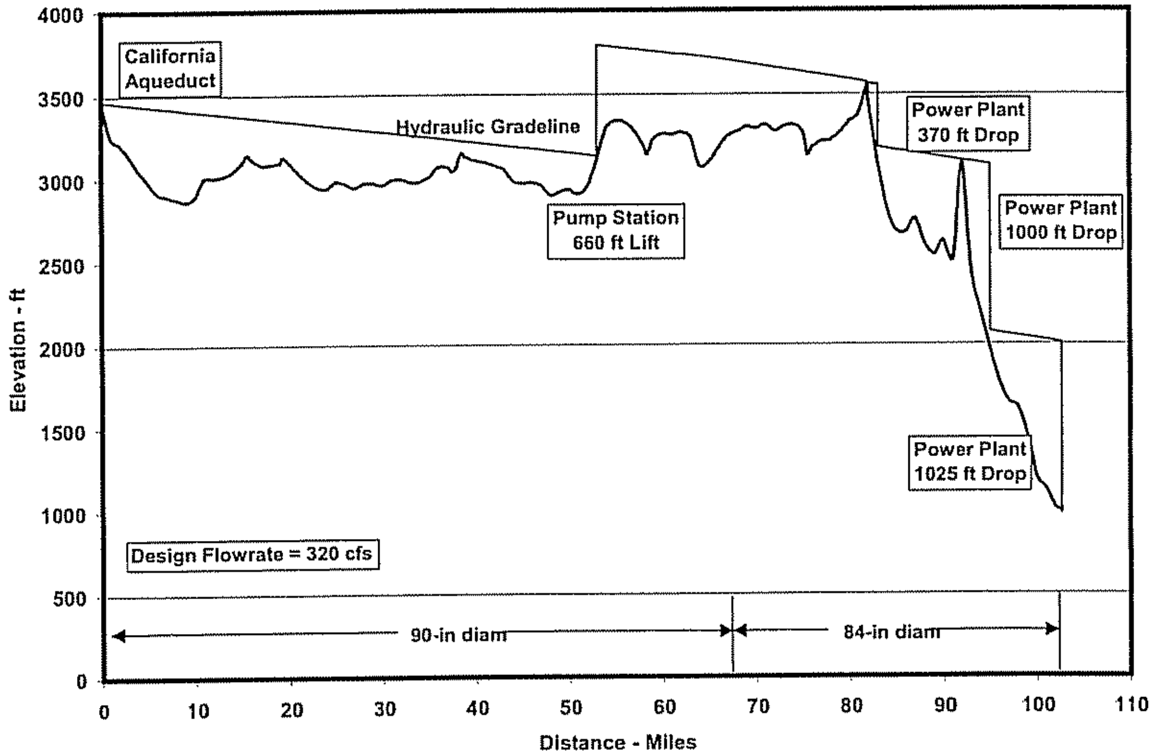


Table I-~~1~~2
Summary of Major Facilities for Aqueduct Alternative

Facility	Capacity			
	120 cfs	**210 cfs**	**320 cfs**	**320 cfs**
Route	Pass Route	Pass Route	Pass Route	Desert Route
Pipelines • To Whitewater Spreading Facility	Length: 55 miles Diameter: 60-in	Length: 55 miles Diameter: 72- in	Length: 55 miles Diameter: 84-in	Length: 67 miles Diameter: 90-in Length: 37 miles Diameter: 84-in
• To Upper Valley Golf Course System		Length: 15 miles Diameter: 48-in	Length: 15 miles Diameter: 48-in	
Mentone Pump Station	Head: 550 ft Capacity: 11,000 HP	Head: 550 ft Capacity: 19,000 HP	Head: 550 ft Capacity: 30,000 HP	
Desert Pump Station				Head: 660 ft Capacity: 33,000 HP
Yucaipa Pump Station	Head: 500 ft Capacity: 10,000 HP	Head: 500 ft Capacity: 18,000 HP	Head: 500 ft Capacity: 27,000 HP	
Cabazon Power Plant	Head: 900 ft Capacity: 10,000 kW	Head: 900 ft Capacity: 16,000 kW	Head: 900 ft Capacity: 25,000 kW	
Power Plant No. 1				Head: 370 ft Capacity: 9,600 kW
Power Plant No. 2				Head: 1,000 ft Capacity: 26,000 kW
Whitewater Power Plant	Head: 540 ft Capacity: 6,000 kW	Head: 470 ft Capacity: 9,000 kW	Head: 450 ft Capacity: 13,000 kW	Head: 1,030 ft Capacity: 27,000 kW

Figure I-4
Hydraulic Profile for Desert Route



- Potential for adverse socio-economic impacts due to increased water costs.

I.1.6 Costs

Since the options evaluated by DWR in 1979 are no longer valid, updated cost estimates have been prepared to determine the financial impact of SWP importation. **Table I-2** summarizes the estimated costs of ~~the three~~ five importation alternatives. ~~Due to the length of the pipeline, the unit cost of water conveyance is lower for the largest capacity options.~~ The first three options are for the San Gorgonio Pass route and show the effects of economies of scale associated with larger pipeline capacity and deliveries. The fourth option presents the costs for the Pass route excluding water for the mid-Valley golf courses but including the capacity required for the SWP Entitlement Transfer. The fifth option presents the costs for the Desert Route with the same capacity as the fourth option. Thus, these latter two options are directly comparable. Due to the significant difference in pipeline length of the Desert Route compared to the San Gorgonio Pass Route, the capital cost of this option is approximately 72 percent greater than that for the Pass Route. Although there is much less pumping and more energy recovery with the Desert Route, the total annual and unit costs of the two routes are within 6 percent of each other. ~~The costs of SWP importation would substantially increase the overall costs of the Water Management Plan.~~

Table I-~~2~~3
Summary of SWP Conveyance Costs for Aqueduct Alternative

Cost Component	Capacity				
	120 cfs Pass Route	210 cfs Pass Route	320 cfs Pass Route	320 cfs Pass Route[3]	320 cfs Desert Route[3]
Capital Cost[1]					
Pipelines	$137,900,000	$216,200,000	$246,700,000	$213,400,000	$418,900,000
Pumping Stations	18,100,000	31,800,000	46,600,000	46,600,000	27,400,000
Power Recovery Plants	20,800,000	31,100,000	44,400,000	44,400,000	72,300,000
Engineering & Administration	26,500,000	41,900,000	50,600,000	45,700,000	77,800,000
Right-of-way	1,600,000	1,600,000	1,600,000	1,600,000	8,700,000
Total Capital Cost	$204,900,000	$322,600,000	$389,900,000	$351,700,000	$605,100,000
Annual Costs[1]					
Amortized Capital	$14,900,000	$23,400,000	$28,300,000	$25,600,000	$44,000,000
Operations Costs	1,700,000	2,400,000	3,300,000	3,300,000	3,700,000
Pumping Costs	8,400,000	14,300,000	22,200,000	22,200,000	13,400,000
Energy Recovery	-3,500,000	-5,700,000	-8,700,000	-8,700,000	-16,000,000
Total Annual Costs	$21,500,000	$34,400,000	$45,100,000	$42,400,000	$45,100,000
Avg. Annual Flow - acre-ft/yr	53,000	90,000	140,000	103,000	103,000
Unit Cost of Delivery[2] – $/acre-ft	$406	$382	$322	$411	$455

1 Costs in year 2000 dollars.
2 Unit cost of delivery does not include conveyance to individual golf courses.
3 Excludes delivery to mid-Valley golf courses.

The impact of incorporating importation of SWP water into the Water Management Plan is discussed at the end of this appendix.

In addition to the direct costs for conveyance facilities, there are lost opportunity costs associated with the Desert Route option. Current SWP cost allocations for CVWD and DWA are based upon taking delivery at the Devil Canyon Afterbay. A change in the diversion point to the East Branch at the Mojave River would result in the loss of energy generation at the Devil Canyon Power Plant on the SWP water deliveries of CVWD and DWA. At this plant, approximately 1,400 ft of head are recovered. Since this generation would be lost, the benefit of the energy recovery for the Desert Route would be reduced adding about $67/acre-ft to the cost of this option. This could increase the annual cost by nearly $7 million.

~~I.1.7 Evaluation~~

~~The costs and the environmental impacts of the SWP importation alternatives would be substantial. The cost of implementing the smallest SWP importation option would increase the costs of the Water Management Plan by more than 50 percent. The option involving importation of all SWP water would more than double the cost of the Plan. This level of annual expenditure is about one half of the current District budget. Based on costs, the SWP importation options are economically infeasible.~~

~~The potential environmental impacts of the SWP importation options would also be profound. Hundreds of acres of habitat would be disturbed by construction of pipelines and related facilities. Increased energy usage may have an adverse effect on the power grid and could require construction of new power generation facilities. Groundwater quality in the Upper Valley would continue to degrade, but at a lower rate than would occur with the Proposed Project. No water quality benefit would be achieved in the Lower Valley.~~

~~In summary, the SWP importation alternative is considered infeasible. It is therefore not considered further in the EIR.~~

I.2 ALTERNATIVE 5 — DESALINATION OF COLORADO RIVER WATER

Desalination of Colorado River water could provide a groundwater quality benefit by reducing the TDS concentration of imported water. This could potentially minimize or eliminate the water quality impacts of the Proposed Project. The basic concept would involve desalination of some or all of the Colorado River water imported to the Coachella Valley to be consistent with the average groundwater quality of about 300 mg/L of TDS.

I.2.1 Treatment Concept

The treatment process used would likely be reverse osmosis (RO). In the RO process, salty water is forced through semi-permeable membranes that allow the water molecules to pass through while retaining the larger salt ions. The level of salt rejection is a function of the type of membrane used and the desired water flux through the membrane. Typically, higher salt rejection results in lower water fluxes and vice versa. Process design typically involves multiple stages of treatment where the rejected (salty) water is passed through subsequent membranes to improve the water recovery. The product water typically is very low in salt (over 90 percent removal) and is blended with untreated water to achieve the desired water quality. Because the membranes are easily fouled (clogged) by fine particulates in the water, pretreatment using some form of filtration is needed. The process produces brine that must be disposed of in an environmentally sound manner. The RO process is proven technology that is commonly used to treat brackish water. Brine disposal would be a major problem in the Coachella Valley.

The level of RO treatment required depends on the quality of the source water. Both Colorado River Aqueduct (SWP Exchange) and Coachella Canal water are relatively low in TDS (670 mg/L and 800 mg/L, respectively) and would be treated to achieve a blended quality of approximately 300 mg/L TDS. For this analysis, the treatment processes would consist of conventional water filtration (coagulation, flocculation, sedimentation and filtration), and two-stage RO treatment followed by brine recovery to minimize the volume of brine. For both waters, about 97 percent of the influent flow is recovered. Additional water would need to be imported to replace the amount of brine flow.

I.2.2 Capacity Options

There are several options available for desalination of Colorado River water:

1. Desalinate all Colorado River water prior to use (both current and future). This option would require the construction of two desalters; one on the Coachella Canal and the other on the Whitewater River near Windy Point.

2. Desalinate all "new" Colorado River water (additional imported water from the Coachella Canal and SWP Exchange). This option would require construction of at least two desalters; one located on the Coachella Canal and the other on the Whitewater River near Windy Point. Additional desalters may be required to supply Canal water users in the middle of the Valley. Modifications to the Canal water distribution system would also be required to separate the current untreated from the future desalinated water deliveries.

3. Desalinate all Colorado River water (both current and future) supplied to areas where groundwater is unconfined. This option would require construction of three or more desalters located in the Oasis area, the mid-Valley area north of Indio, and near Windy Point. Modifications to the Canal water distribution system would also be required to deliver desalinated water to users overlying the unconfined aquifers.

4. Desalinate all "new" Colorado River water supplied to all areas where groundwater is unconfined. This option would require similar facilities to Option 3 but with smaller capacities.

5. Desalinate all "new" Colorado River water supplied for groundwater recharge, in-lieu use in the Upper Valley and the Oasis areas where groundwater is unconfined. This options would also require construction of at least three desalters; one located on the 97.1 Lateral, one west

of Indio and one at Windy Point. The capacities would be somewhat smaller than for Option 4.

6. Desalinate all Colorado River water used for groundwater recharge only. This option would require the construction of two desalters: one located on the 97.1 lateral and one at Windy Point. The capacities would be similar to those of Option 5.

Table I-3 shows the amounts of water associated with each option. The distinction between these options relates to the number and capacity of facilities and the expected effect on groundwater quality. Option 1 would substantially reduce the amount of salt contributed to the Coachella Valley but would need to treat the most water. Option 5 would reduce the salt load the lowest amount and would treat the least amount of water.

Table I-34
Colorado River Desalination Options

Option	Use	Average Annual Delivery (acre-ft/yr)		
		SWP Exchange	Coachella Canal	Total
1	Direct Use	37,000	361,000	398,000
	Recharge	103,000	80,000	183,000
	Total	140,000	441,000	581,000
	Brine Flow	4,000	14,000	18,000
	Influent Flow	144,000	455,000	599,000
2	Direct Use	37,000	83,000	120,000
	Recharge	53,000	80,000	133,000
	Total	90,000	163,000	253,000
	Brine Flow	3,000	5,000	8,000
	Influent Flow	93,000	168,000	261,000
3	Direct Use	37,000	199,000	236,000
	Recharge	103,000	80,000	183,000
	Total	140,000	279,000	419,000
	Brine Flow	4,000	9,000	13,000
	Influent Flow	144,000	288,000	432,000
4	Direct Use	37,000	56,000	93,000
	Recharge	53,000	80,000	133,000
	Total	90,000	136,000	226,000
	Brine Flow	3,000	4,000	7,000
	Influent Flow	93,000	140,000	233,000
5	Direct Use	37,000	23,000	60,000
	Recharge	53,000	80,000	133,000
	Total	90,000	103,000	193,000
	Brine Flow	3,000	3,000	6,000
	Influent Flow	93,000	106,000	199,000
6	Direct Use	0	0	0
	Recharge	103,000	80,000	183,000
	Total	103,000	80,000	183,000
	Brine Flow	3,000	3,000	6,000
	Influent Flow	106,000	83,000	189,000

For this evaluation, Options 1 and 5 are considered since they bracket the range of capacities, costs and potential impacts. In addition, Option 6 is considered for comparison with the SWP options of delivering recharge water only. The treatment capacities~~y~~ for direct deliveries ~~is~~ are based on a 150 percent peaking factor to provide sufficient water to meet peak summer demands under wet year flow conditions. For recharge only options, the treatment capacity is based on a peaking factor of 1.5 for the Whitewater facility, which allows delivery of recharge water over an 8 month off-peak period. This is necessary because Metropolitan typically makes Exchange water deliveries in the lower demand months. For the Lower Valley facilities, a peaking factor of 2.0 is used because recharge deliveries must be made in the six low demand months. **Figure I-3** shows potential locations for desalters and brine lines for these two options.

I.2.3 Brine Disposal

The desalination process results in a concentrated solution (brine) that must be disposed in an environmentally acceptable manner. The concentrate from the basic RO process has a TDS of 4,400 to 5,200 mg/L. Since there is a substantial amount of concentrate (about 10 percent of total flow), brine recovery is considered to reduce the volume of brine produced and recover additional water. This process reduces the brine flow to about 3 percent of the total flow and triples the TDS of the brine to 14,000 to 17,000 mg/L.

Two disposal options are considered. Option A involves the use of "on-site" evaporation ponds constructed near each treatment facility. The ponds would be lined with an impervious material to prevent groundwater contamination. Option B involves the use of "off-site" brine evaporation ponds located near the Salton Sea. Under this option, brine produced by individual plants would be pumped into a 47-mile pipeline running the length of the Coachella Valley parallel to the Whitewater River/CVSC and discharged to the Salton Sea. To mitigate for the salt load added to the sea, brine evaporation ponds would be constructed near the Sea to evaporate and remove an amount of salt equal to the salt content of the brine. This salt offset approach near the Sea reduces the size of the evaporation ponds by a factor of about three and may allow the use of unlined ponds, as percolation is minimal in this clayey seaside area. Unlined ponds may be an order of magnitude less expensive to construct than lined ponds. Following evaporation, the salt removed must be disposed. The location of ultimate salt disposal is speculative.

Option 1 would produce approximately 18,000 acre-ft/yr of brine having a TDS of about 14,000 to 17,000 mg/L. If this brine flow were disposed in on-site evaporation ponds, approximately 3,500 acres (5.5 sections or square miles) of pond surface area would be required. Disposal of the brine to the Salton Sea and use of a salt offset would require about 1,300 acres (2 sections) of land near the sea for evaporation ponds. Option 5 would produce about 6,000 acre-ft/yr of brine with similar quality characteristics. Disposal of the brine in on-site ponds would require about 1,300 acres of pond area. Brine disposal to the Sea with a salt offset would require about 540 acres (0.8 sections) of evaporation ponds. In each case, the dried salt would need to be removed periodically and disposed. Option 1 would produce about 390,000 tons of salt per year while Option 5 would produce about 135,000 tons of salt per year.

I.2.4 Environmental Impacts

The environmental impacts associated with the desalination options are:

- Permanent use of at least 500 to 3,500 acres of land for brine storage and evaporation and an additional 100 to 300 acres of land for treatment facilities and rights-of-way. Permanent modifications of landforms near pumping and power recovery locations.
- Changes in water absorption rates, drainage patterns and runoff at treatment plant sites, brine evaporation ponds and along pipeline alignments.
- Need for an additional 6,000 to 17,000 acre-ft/yr of imported water to make up for brine production and evaporation.
- Significant loss of habitat, plant and animal resources at treatment and brine evaporation sites and along the conveyance pipeline routes. Potential impact on endangered species, especially if on-site lined brine evaporation ponds are constructed.
- Potential loss of cultural resources along pipeline routes and at plant and evaporation sites.
- Increased noise during construction.
- Air quality impacts from construction equipment and dust during construction; additional air quality impacts from increased energy generation for treatment and pumping. Potential adverse air quality impacts associated with brine evaporation.
- Temporary disruption of traffic patterns and increased traffic congestion during construction activities.
- Net energy requirement of about 1,000 to 1,200 kWh/acre-ft. About 20 to 60 megawatts of electrical generation capacity would be required for reverse osmosis treatment. Potential impact on existing energy infrastructure for both pumping and recovered energy.
- Gradual reduction in salt load to Salton Sea associated with drain flows to 154,000 tons/year compared to 462,000 tons/year for the Proposed Project.
- Reduced salt load to the Coachella Valley and associated reduction in water quality degradation. In the Upper Valley, the average TDS of groundwater would increase by 170 to 220 mg/L compared to 320 mg/ for the Proposed Project. In the Lower Valley, the average TDS of groundwater would increase by 120 to 260 mg/L compared to 315 mg/ for the Proposed Project. These reductions represent water quality improvements compared to the Proposed Project. However, even desalinating all imported water would not halt groundwater quality degradation.
- Potential for adverse socio-economic impacts due to increased water costs.

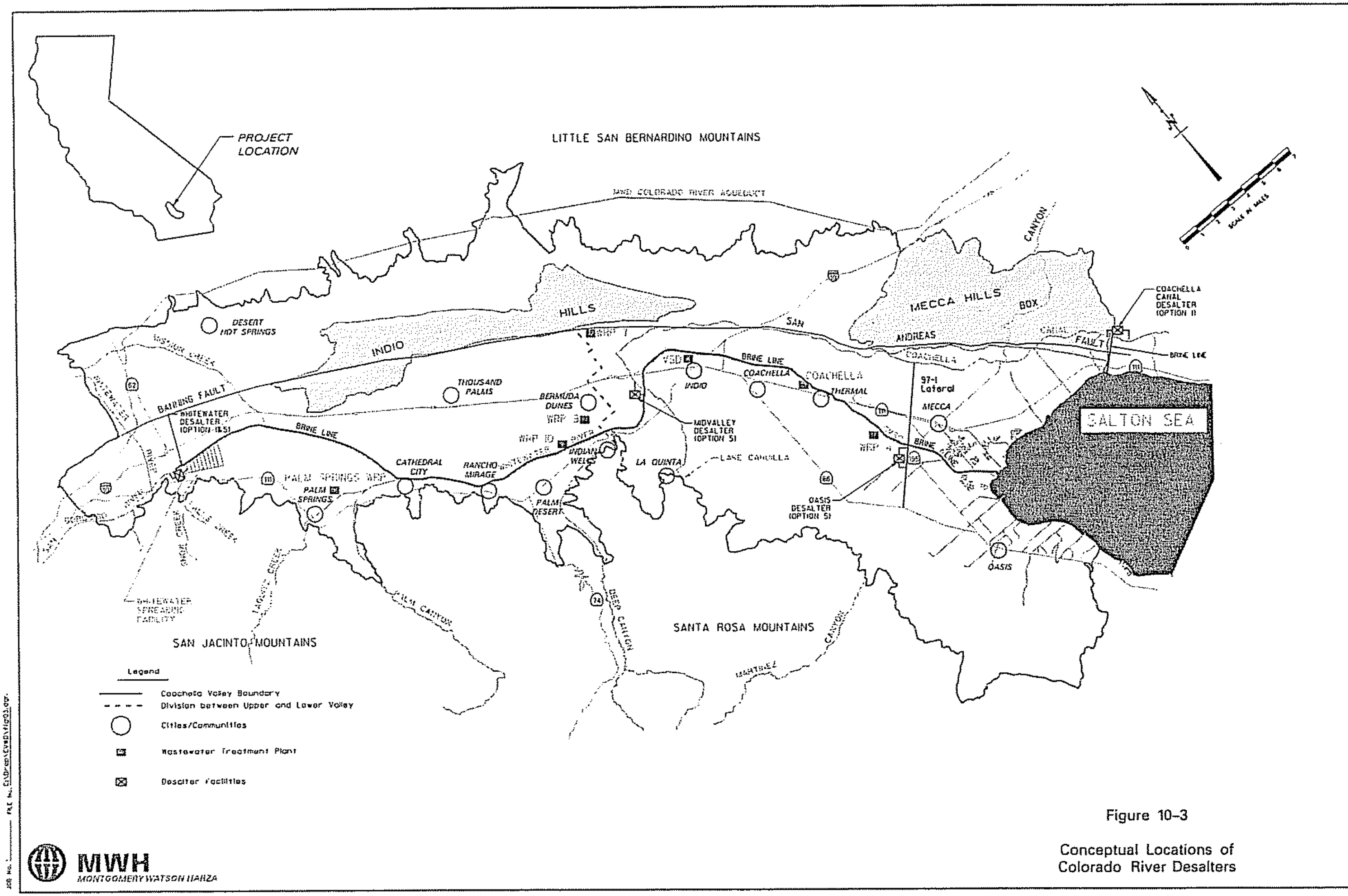


Figure 10-3

Conceptual Locations of Colorado River Desalters

I.2.5 Costs

The estimated costs for desalination treatment are based on analysis of RO treatment and experience with plants that treat similar quality water. The costs have been scaled up to the capacities required for this application. As discussed above, two options are presented to bracket the range of costs involved in desalination, Option 1 and Option 5 as presented in **Table I-34.** The costs of brine disposal are presented for each option. Note: The cost estimates presented for desalination have been adjusted from the Draft PEIR to reflect estimating errors for water treatment and desalination costs. The previous costs omitted about 65 percent of the required desalination capacity.

Table I-34 presents a summary of the costs for each option and sub-option evaluated. The capital cost of Option 1 ranges from about ~~$560 million~~ $1.1 billion to ~~$1.19~~ $1.73 billion. This substantial cost difference results primarily from the cost of lined evaporation ponds and the greater acreage required to evaporate the more dilute brine flows. The capital cost of Option 5 ranges from ~~$279~~ $575 million to ~~$479~~ $850 million. Again, the difference is due to the use of lined ponds and the greater acreage required. Option 6, which includes desalination for recharge only, adds capacity to accommodate the SWP Entitlement Transfer and other future transfers. Annual costs range from about ~~$44~~ $67 million to ~~$155~~ $200 million. Unit costs range from ~~$184~~ $258 to ~~$330~~ $537/acre-ft, on top of the Water Management Plan implementation costs.

~~I.2.6 Evaluation~~

~~The costs of the desalination alternatives are substantial. The cost of implementing the smallest desalination option would more than double the costs of the water management plan. The larger program would increase the cost of the plan by more than 170 percent. This level of annual expenditure is 15 percent greater than the current district budget. Based on costs, the desalination options are economically infeasible.~~

~~Similarly, the potential environmental impacts of the desalination options are significant and adverse. Hundreds of acres of desert habitat could be lost to brine evaporation ponds. Increased energy usage would have a significant adverse effect on the power grid and could require construction of new power generation facilities. Groundwater quality would continue to degrade, but at a much lower rate than would occur with the Proposed Project. Salt disposal after evaporation could create an adverse impact at the site of disposal.~~

~~In summary, the desalination alternative is considered infeasible. It is therefore not evaluated further in the PEIR.~~

Table I-45
Summary of Desalination Costs

Cost Component	Option 1 – Treat All Imported Water		Option 5 – Treat New Imported for Recharge, Upper Valley Golf Courses and Oasis		Option 6 – Treat All Imported for Recharge Only	
	On-Site Lined Brine Ponds	Off-site Un-lined Brine Ponds	On-Site Lined Brine Ponds	Off-site Un-lined Brine Ponds	On-Site Lined Brine Ponds	Off-site Un-lined Brine Ponds
Capital Costs						
Conventional Water Treatment Plants	$103,600,000	$103,600,000	$92,600,000	$92,600,000	$80,000,000	$80,000,000
Reverse Osmosis Plants	722,200,000	722,200,000	296,100,000	296,100,000	342,400,000	342,400,000
Pumping Stations	11,300,000	11,900,000	12,000,000	12,300,000	15,200,000	15,800,000
Brine Disposal Pipeline	0	35,500,000	0	29,900,000	0	29,900,000
Brine Evaporation Ponds	531,000,000	24,600,000	189,000,000	8,600,000	243,000,000	10,500,000
Engineering and Administration	205,100,000	134,700,000	88,500,000	65,900,000	102,100,000	71,800,000
Land Acquisition	152,400,000	63,200,000	54,400,000	22,400,000	69,600,000	27,200,000
Total Capital Costs	$1,725,600,000	$1,095,700,000	$732,600,000	$527,800,000	$852,300,000	$577,600,000
Annual Costs						
Amortized Capital	$125,300,000	$79,600,000	$53,500,000	$38,300,000	$61,900,000	42,000,000
Operations	13,700,000	8,800,000	6,000,000	4,300,000	6,900,000	4,700,000
Chemicals	5,500,000	5,500,000	1,900,000	1,900,000	2,500,000	2,500,000
Energy	40,900,000	40,900,000	16,900,000	16,900,000	20,500,000	20,500,000
Membrane Replacement	15,300,000	15,300,000	5,500,000	5,500,000	6,700,000	6,700,000
Total Annual Costs	$200,700,000	$150,100,000	$83,800,000	$66,900,000	$98,500,000	$76,400,000
Average Annual Flow – acre-ft/yr	581,000	581,000	193,000	193,000	183,000	183,000
Unit Cost of Water [1]	$345/acre-ft	$258/acre-ft	$433/acre-ft	$347/acre-ft	$538/acre-ft	$417/acre-ft

Notes:
1. Unit cost of water includes filtration, desalination, brine disposal, and product water pumping. Cost of delivery piping and related pumping is additional.

I.3 ALTERNATIVE 6 — DUAL USE OF THE COLORADO RIVER AQUEDUCT

One commenter provided an interesting option of conveying SWP water for recharge in the Coachella Valley by the dual use of the Metropolitan's Colorado River Aqueduct (CRA) Under this concept, a pipeline and pumping station would be constructed to convey SWP water from Lake Perris to the CRA near the western portal of the San Jacinto Tunnel. During periods when the CRA is not in use, SWP water would be pumped into the CRA to flow in the reverse direction to the Coachella Valley.

Evaluation of this option based on several considerations. The CRA is always in use for conveying Colorado River water to Southern California (except for short periods when maintenance is performed). The design flowrate of the CRA is 1,800 cfs (about 1.3 million acre-ft/yr) toward the west. Metropolitan is currently delivering approximately 1.25 million acre-ft/yr of Colorado River water. Although Metropolitan's current firm deliveries from the Colorado River are about 660,000 acre-ft/yr, Metropolitan is developing and implementing plans to maintain as close to full deliveries as possible. These projects include the water transfers under the QSA, Palo Verde land fallowing, several interstate and desert storage projects and surplus Colorado River water for the next 15 years.

To deliver an average annual SWP flow of 103,000 acre-ft/yr (174,200 acre-ft/yr maximum annual) to CVWD and DWA, several factors must be considered including the SWP contractual limitations and spreading ground capacity. The SWP contract limits peak month flow to 1.32 times the average annual flow. This effectively limits the maximum supply from the SWP to 318 cfs as described in Section I.1. At this maximum contractual flowrate, 164 days of operation would be required to make average annual deliveries. This would restrict Metropolitan's use of its own aqueduct to 201 days per year and limit deliveries to 718,000 acre-ft/yr (57 percent of current). Delivery of the maximum amount of water to CVWD and DWA would limit Metropolitan to 89 days per year or 317,000 acre-ft/yr (25 percent of current). Clearly, this approach would not be acceptable to Metropolitan.

If the SWP contractual peaking limitation can be waived, a higher flowrate may be possible. The next capacity limitation is the Whitewater Spreading Facility which has a maximum recharge capacity of 300,000 acre-ft in a single year (based on operational experience) or a continuous flowrate of 415 cfs. This flowrate does not include any allowance for recharge basin maintenance. Delivery of the average CVWD and DWA SWP recharge water supply at the maximum recharge rate of 415 cfs requires a 126 day operating period. Reversal of flow for this period of time would effectively limit Metropolitan's operations to 239 days per year. This would limit Metropolitan to a maximum annual delivery of 854,000 acre-ft/yr (68 percent of current capabilities). During years of maximum supply, the CVWD-DWA would require delivery for 212 days. This would limit Metropolitan's use to 153 days or 546,000 acre-ft/yr (43 percent of current). While expansion of the recharge basins may be possible, historical operation in the mid-1980s indicated that water levels would rise close to the ground surface at these high rates. Thus, expansion may be limited by hydrogeologic constraints. In addition, environmental impacts from construction of new recharge basins, such as loss of dune sand replenishment for fringe-toed lizard habitat, may be difficult to resolve.

The SWP Santa Ana Pipeline was designed to convey 444 cfs from the Devil Canyon Afterbay in San Bernardino to Lake Perris. The capacity of this pipeline is insufficient to meet Metropolitan's needs in Riverside and San Diego counties. Metropolitan is currently constructing the Inland Feeder, which will have a capacity of 1,000 cfs when it is completed in 2007. The Inland Feeder will allow Metropolitan to make full use of its capacity in the East Branch of the California Aqueduct. CVWD and DWA do not have capacity rights in either of these pipelines and obtaining such capacity would be difficult.

Finally, the existing CRA pipeline probably cannot take the added pressure required for reverse flow. The CRA was designed in the 1930s for falling hydraulic gradient. This means that the CRA was designed with a hydraulic gradeline that closely approximates the ground surface elevation. Little allowance was provided for pressurization. In addition, the San Jacinto Tunnel, which accounts about 14 miles of the distance to the Whitewater turnout leaks significant amounts of water and may not have the structural integrity to handle the additional pressure (over 100 ft) required to force water to the Coachella Valley. Since it is the sole source of Colorado River water for Southern California, shutting down the tunnel for extended periods of time to accomplish structural modifications would present significant operational problems for Metropolitan.

Based upon these considerations, there are significant technical and operation issues associated with this alternative. Discussion of this approach with the management of Metropolitan has indicated to CVWD that they would not consider such a proposal. Therefore, this alternative is dropped from further consideration.

I.4 ECONOMIC EVALUATION

The economic evaluation of the water quality improvement alternatives is considered in terms of their effects on the current CVWD budget and the future costs of the Water Management Plan and SWP Entitlement Transfer.

I.4.1 Existing CVWD Expenditures

The current (FY 2000-01) annual budget for CVWD is approximately $106 million as shown in **Table I-5**. Of this total, $7 million is expended on irrigation water service, $45 million on domestic water service and $21 million on general expenses that include SWP water purchases.

Table I-5
Existing CVWD Expenditures – Fiscal Year 2000-01

	Irrigation	Domestic	Sanitation	Stormwater	General	Total
Revenues	$7,457,804	$45,105,987	$23,070,359	$8,524,323	$21,566,640	$105,725,113
Expenditures						
Oper. & Maint.	$3,413,915	$19,589,590	$8,631,616	$898,695	0	$32,533,816
Engg. Admin & Gen	3,233,604	11,108,451	4,871,650	2,867,411	8,444,160	$30,525,276
Contract & Bond Pymts	418	169,265	3,555,465	1,754,526	12,769,866	$18,249,540
New Construction	613,780	6,329,446	4,930,514	160,119	734,825	$12,768,684
Reserves	196,087	7,909,235	1,081,114	2,843,572	-382,211	$11,647,797
Total	$7,457,804	$45,105,987	$23,070,359	$8,524,323	$21,566,640	$105,725,113

Reference: CVWD Annual Report 2001.
1. Includes groundwater replenishment assessment fees – well owners' proportionate share of the cost of importing water to replenish the groundwater basin.
2. Purchases of 7,512 acre-ft of additional SWP water received in FY 2000-01 funded from reserves.

I.4.2 Anticipated Water Management Plan Expenditures

Section 7 of the CVWD Water Management Plan presented estimated annual expenditures in five-year increments for the implementation of the Water Management Plan. These costs are summarized in **Table I-7**. Average annual expenditures for water management plan activities and new water source costs (such as the IID-CVWD transfer and the SWP entitlement transfer) are expected to add about $20,000,000 per year initially, and increasing to $35 to 47 million in future years. The average annual cost over the 32 years of the Management Plan is $40 million. These added costs will increase total District expenditures by a factor of 19 to 43 percent.

Since much of these new expenditures are required for domestic, irrigation and general expenses, these components of the cost will increase more rapidly than the sanitation and stormwater operations. Currently, CVWD has not determine how these future costs will be allocated among users.

I.4.4 State Water Project

The cost of implementing the smallest SWP importation option would increase the average cost of the Water Management Plan by more than 50 percent from $40 million to about $62 million per year. The options involving importation of all SWP water for recharge would more than double the cost of the Plan from $40 million to $82 - 85 million. This level of annual expenditure is about 80 percent of the current District total budget ($105,700,000 for Fiscal Year 2001) and more than three times the current domestic water budget. If all costs were borne by domestic water users, the water rates might be expected to more than double.

The potential environmental impacts of the SWP importation options would also be significant. Hundreds of acres of habitat would be disturbed by construction of pipelines and related facilities. Although mitigation may reduce these impacts permanent habitat loss is still expected.

Increased energy usage for the San Gorgonio Pass route may have an adverse effect on the power grid and could require construction of new power generation facilities. However, the Desert route results in the net generation of energy. Groundwater quality in the Upper Valley would continue to degrade, but at a lower rate than would occur with the Proposed Project. No water quality benefit would be achieved in the Lower Valley because all of the SWP water would be utilized to eliminate overdraft in the Upper Valley.

I.4.4 Desalination

The costs of the desalination alternatives are substantial. The cost of implementing the smallest desalination option would increase the annual costs of the water management plan by a factor of 2.7 times ($40 million to $107 million). The largest program would increase the annual cost of the plan by a factor of six times ($40 million to $240 million. If the recharge only options were implemented the costs would nearly triple ($40 million to $116 million). This level of annual expenditure is 10 percent greater than the total current district budget ($106 million to $222 million) and more than 2.5 times the current water budgets ($74 million to $190 million. Based on costs, the desalination options are considered to be economically infeasible.

Similarly, the potential environmental impacts of the desalination options are significant and adverse. Hundreds of acres of desert habitat could be lost to brine evaporation ponds. Increased energy usage would have a significant adverse effect on the power grid and could require construction of new power generation facilities. Groundwater quality would continue to degrade, but at a much lower rate than would occur with the Proposed Project. Salt disposal after evaporation could create an adverse impact at the site of disposal.

I.4.5 Combination Option

Another potential option considered involved SWP importation facilities to meet the Upper Valley recharge needs and desalination to meet the Lower Valley recharge needs. SWP importation via the San Gorgonio Pass Route is less expensive than the Desert Route, hence it appears preferable for this evaluation. The estimated capital costs for this SWP option are $352 million with total annual costs of $42 million per year. The estimated costs for Lower Valley recharge desalination (Desalination Option 6) were separated from the total costs presented in **Table I-6**. The capital cost for this facility would be $236 million and the total annual cost would be $32 million per year based on off-site brine disposal. The combined capital cost for this option is $588 million with total annual costs of $74 million. These costs are comparable with those of the recharge desalination option ($74 million versus $76 million). Therefore, from a cost standpoint the combination option would be expected to have a similar impact on water costs as the desalination approach.

The environmental impacts of the SWP importation would be the same as described previously. However, the impacts of brine disposal would be reduced by about 55 percent.

Table I-6
Projected Water Management Plan Expenditures

Management Plan Element	Year						
	2000-2005	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035
Water Conservation	$600,000	$1,792,000	$1,855,000	$1,943,000	$2,034,000	$2,087,000	$2,177,000
Groundwater Recharge							
Upper Valley	$6,554,000	$9,022,000	$8,760,000	$8,709,000	$8,477,000	$8,375,000	$8,809,000
Lower Valley	$2,067,000	$313,000	$3,543,000	$1,429,000	$2,037,000	$2,081,000	$2,081,000
Total Groundwater Recharge	$8,621,000	$9,335,000	$12,303,000	$10,138,000	$10,514,000	$10,456,000	$10,890,000
Source Substitution							
Recycled Water to UV GC's	$2,334,000	$1,128,000	$1,224,000	$1,331,000	$1,402,000	$1,441,000	$1,478,000
SWP Exchange for UV GC's	$0	$8,130,000	$3,954,000	$1,611,000	$1,611,000	$1,611,000	$1,611,000
Canal water for Ag. ID-1	$263,000	$411,000	$527,000	$2,106,000	$3,931,000	$1,083,000	$1,086,000
Canal water for GC's ID-1	$237,000	$204,000	$23,000	$23,000	$23,000	$23,000	$23,000
Desalted Ag drains OID-1	$0	$0	$6,511,000	$1,265,000	$9,209,000	$2,809,000	$2,824,000
Canal water for Domestic Use	$0	$0	$0	$0	$0	$3,313,000	$859,000
Total Source Substitution	$2,834,000	$9,873,000	$12,239,000	$6,336,000	$16,176,000	$10,280,000	$7,881,000
Colorado River Water Transfers	$0	$535,000	$1,872,000	$3,210,000	$5,035,000	$6,925,000	$8,245,000
SWP Entitlement Transfers	$8,307,000	$16,241,000	$15,476,000	$14,009,000	$12,519,000	$11,354,000	$11,169,000
Total Water Management Plan	$20,362,000	$37,776,000	$43,745,000	$35,636,000	$46,278,000	$41,102,000	$40,362,000

I.5 CONCLUSION

All of the options evaluated in this appendix have the objective of reducing the salinity impacts of Colorado River water use in the Coachella Valley. Each of the options add significantly to the costs of the Water Management Plan and could result in the District's expenditures increasing from \$106 million per year currently to \$220 million. Implementation of the Water Management Plan without the salinity control measures would increase the District's costs to \$146 million per year. CVWD has not evaluated the potential financial impacts of the plan on individual water users. Portions of the costs of the Plan are expected to be borne by groundwater pumpers through increased replenishment assessments, by irrigation and domestic water customers through increased rates.

Honors and Memberships

1940	Partial Pulitzer Scholarship
1955	American Geophysical Union - "Best First Paper in Hydrology"
1966	Christian R. and Mary F. Lindback Foundation Award for Distinguished Teaching
1968	Nominated for the Danforth Foundation, E. Harris Harbison Award for Distinguished Teaching
	Nominated for Outstanding Educators of America
1980-81	Geological Society of America, Birdsall Distinguished Lecturer in Hydrogeology
1980	Barney and Estelle Morris Professor of Earth Sciences
1985	School of Earth Sciences Outstanding Teaching Award

Fellow, Geological Society of America
Tau Beta Pi
Sigma Xi, President - Stanford University and Drexel Institute of Technology
Phi Kapp Phi, Treasurer of Drexel Chapter
Committees for American Geophysical Union, National Academy of Science, Geological Society of America, etc.
Philadelophia Geological Soceity, Treasurer
Geological Society of America, Hydrogeology Division, 1970 Second Vice-Chairman
Academic Senate of Stanford University
Chief Marshall of the Drexel Faculty

Undergraduate Courses Taught

Physical Geology
Historical Geology
Engineering Geology
Natural Environment
Static Mechanics
Kinetic Mechanics
History of Science
Fluid Mechanics
Environmental Earth Science
Optimization methods

Graduate Courses Taught

Hydrogeology
Engineering Geology
Rainfall and Runoff
Groundwater Hydraulics
Numerical Methods in Hydrology
Modeling Methods in Hydrology
Evaporation and Transportation
Stream Analysis and Pollution Control
Development of Groundwater Supplies
Finite-element methods

Publications

About 80 publications in hydrology, groundwater, soil moisture and other environmental topics. Books on "Numerical Methods in Subsurface Hydrology" and "Geology in Environmental Planning" (with A.D. Howard).

Research

Extensive research on hydrogeology in the U.S. Geological Survey, at Drexel Institute of Technology, and at Stanford University. Consultant to private concerns and govenment agencies.

State of California Registration

Registered Geologist License #901
Certified Engineering Geologist License #335

RECENT HONORS

1992 Stanford University Gores Award for Teaching

1992 American Geophysical Union Fall Meeting - "The Remson Symposium- 30 Years of Groundwater Modeling"

1993 National Groundwater Association 1993 M. King Hubbert Award for Scientific Contributions to the Groundwater Community

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CLIENTS (Pre-1982)

National Academy of Sciences-National Research Council

North American Rockwell

W.A. Wahler & Assoc.

The Anaconda Co.

Teknekron, Inc.

International Engineering Co.

Atlantic-Richfield Hanford

TRW

Koretsky-King Assoc. (Pescadero, Ca.)

San Mateo Co.

Rio Blanco Oil Shale

Environmental Science Assoc.

Sonoma, Ca.

Agricultural & Industrial Minerals, Inc.

Walnut Creek, Ca.

Contra Costa Co., Ca.

Amex, Inc.

Beryllium Corp. Americal

Morristown, N.J.

Philadelphia Board of Education

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CLIENTS (1982-1988)

U.S. Geological Survey

Battelle Office of Crystalline Repository Development

Battelle Office of Nuclear Waste Isolation

U.S. Department of Justice

Science Applications International Corporation

Oak Ridge National Laboratory

University of San Paulo, Brazil

Peoples Republic of China

Rockwell Hanford Corporation

Environmental Resources Management Southeast, Inc.
(Velsicol Chemical Corporation)

John Lowry & Associates

Monterey County Flood Control District

Anderson-Nichols Inc.

Shute, Mihaly & Weinberger

Aqua Terra Consultants

Atchinson & Anderton

Thornton, Taylor & Dunne

Sunlaw Energy Corp.

WZI Inc.

Adler, Kaplan & Begy

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Basset & Morrison
Alexander, Millner & McGee (City of Oakland)
Earth Sciences Associates (East Bay MUD)
Brown & Caldwell
City of Benicia
U. S. Department of Justice (New Reservations)
Alton M. Chamblis (Benson Ridge Site)
U.S. DOE
City and County of Honolulu
Tucson Airport Superfund Site
Metropolitan Water District of Southern California
Morgan, Ruby, et al. (San Mateo County)
Minasian, et al. (Lompoc case)